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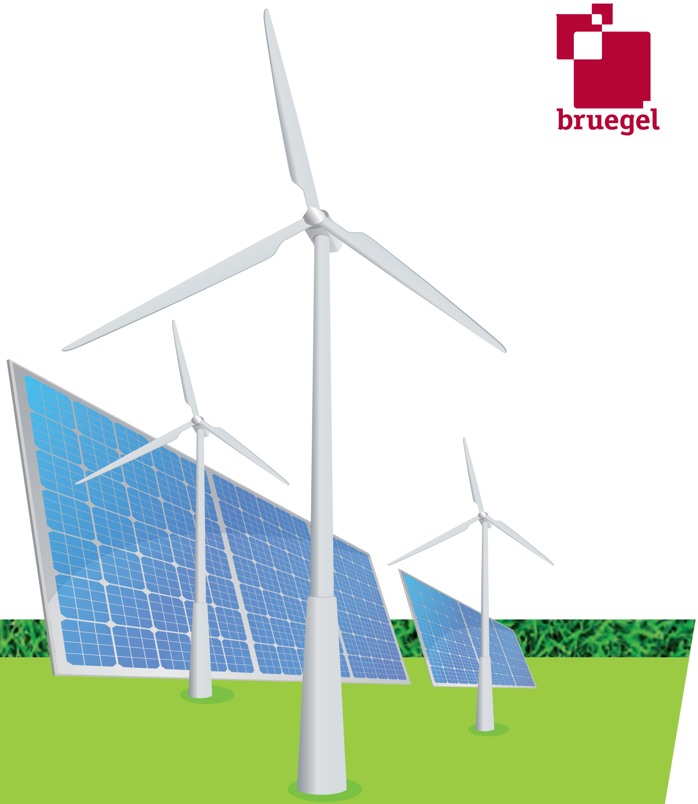

INVESTMENT AND GROWTH IN THE TIME OF CLIMATE CHANGE

Investment and growth in the time of climate change

Economics Department (EIB)/Bruegel

Investment and growth in the time of climate change
By Atanas Kolev, Armin-D. Riess, Georg Zachmann and Edward Calthrop

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Preface

Climate scientists mostly agree that, if current trends continue, global greenhouse-gas emissions are very likely to result in dangerous interference by mankind in the earth's climate. Against this background, the world community has set itself the goal of limiting the increase in the global average temperature by the end of this century to no more than 2°C compared to pre-industrial times. To get there, global emissions will have to fall substantially.

Largely focussing on the European dimension of this goal, this report considers investment and economic growth on a greenhouse-gas emissions trajectory that breaks with the past. Investment-related questions that this report pursues include: how should Europe properly balance investment in mitigating greenhouse-gas emissions and adaptation to climate change? How urgent is it to invest in both? How do global cooperation on climate action and fear of climate catastrophe impact on the balance between mitigation and adaptation? What are the key obstacles to climate investment? Which policies promise to remove these obstacles and make investment profitable, thereby encouraging investment finance? What are the respective roles of the private and the public sector? Growth-related questions include: how are climate action and economic growth linked and, specifically, what is the role of innovation? Are there only trade-offs between climate action and growth or are there win-wins, too? Can climate action help Europe emerge from its economic crisis? How can climate action be made as growth-friendly as possible?

In addressing these questions, this report takes an economic perspective. More specifically, at the heart of the analysis is the quest for economic efficiency. Not surprisingly for this type of analysis, a key theme running through the report is one of trade-offs and difficult choices that society needs to make. Cognisant of the fact that markets left alone will not make economically efficient choices, another common theme is the role of government policies in bringing about efficient outcomes. Considering trade-offs and government policy together, the key message from this report is that there is unexploited scope for making Europe's climate action more efficient, growth-friendly, and in tune with fiscal constraints.

The report is the result of a joint research effort by the Economics Department of the European Investment Bank and Bruegel. It is our hope that it will help to clarify some of the complexities involved in designing effective policies to address climate change without sacrificing too much economic growth, in a world in which international cooperation on climate action is so difficult to achieve.

Debora Revoltella
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CHAPTER 1

Setting the scene

Edward Calthrop, Atanas Kolev, Armin-D. Riess and Georg Zachmann

1.1 The many facets of climate change

The impact of humans on the planet has been so great that scientists have coined a new term for the geological era mankind has entered in to – the Anthropocene: the age of man. Arguably, manmade climate change is, and will continue to be, the most prominent feature of this era.

The assessment of climate change – in particular, how, when, and where to tackle it – is informed by natural and social sciences. But as Hulme (2009) lucidly sets down, many other factors are also at work: people's perceptions of risk; their beliefs and fears; and how the media, vested interests and society shape and communicate information about climate change. Views depend, too, on what people see as being at stake: the welfare of nations, the material well-being of citizens, national sovereignty, ecosystems, the distribution of income and wealth – within and across nations and, equally important, across generations. What is more, opinions depend on whether or not it is ethically and politically acceptable to consider trade-offs and, ultimately, choose winners and losers.

Cognisant of the many facets of climate change, this report looks through the lens of economics, that is, the social science that measures the economic impact of climate change and the costs and benefits of trying to mitigate it and adapt to it. Climate change insights from the natural sciences are a point of departure for this perspective. Moreover, the economics of climate change typically account for people's risk perceptions, while the issue of *inter*generational equity is central to the economics of climate change. This is true, too, for trade-offs between the welfare of a nation broadly defined and the material well-being of its citizens. All these aspects will be explicitly or implicitly accounted for in this report. By contrast, issues of *intra*generational equity – within nations and across them – do not feature explicitly in this report. It follows that in contrast to many other studies, this report is silent on both the many challenges climate change poses for developing countries and how development cooperation between rich and poor nations must address mitigation and adaptation in the developing world. Excluding these issues from this report does not mean they are considered unimportant. Rather, the intention is to keep the scope of the analysis manageable. In a similar vein, a European perspective is offered, though many of the insights apply equally to other countries.

Focusing on economic efficiency and Europe usefully limits the scope of the report, but it still leaves too broad an agenda and, thus, it makes sense to be yet more selective. As the title of the report indicates, the purpose is to consider investment and economic growth in the time of climate change. From an investment perspective, issues for study include the balance between investment in mitigating greenhouse-gas emissions and adaptation to climate change; the urgency and timing of investing in both; investment needs and their distribution across sectors; obstacles to investment; policies to remove them and make investment profitable, thereby encouraging investment finance; and the respective roles of private and public investment.

From a growth perspective, issues of interest include the link between climate action and economic growth – specifically, possible trade-offs and win-wins; the short-term and the long-term dimensions of this link – including the scope for climate action to help Europe emerge from its economic crisis; the challenge of managing zero growth in Europe (and other advanced economies) should zero growth become inevitable in a world with environmental limits to growth and poor countries' undeniable aspirations to attain higher living standards; the importance of innovation as an interface between climate action and economic growth; the opportunity cost of allocating public finance to climate-action research and development instead of other worthwhile R&D endeavours; and the need to make climate action as growth-friendly as possible.

The chapters that follow analyse many of these investment and growth issues. More specifically, in addition to reviewing adaptation priorities for Europe, chapter 2, *Mitigate, adapt, or endure: a question of balance*, illustrates key factors that determine the optimal balance between climate-change mitigation and adaptation. The findings following from this illustration show how the optimal balance between mitigation and adaptation depends on the magnitude of climate-change impacts and the relative weight society attaches to future costs and benefits relative to present ones. Moreover, the findings illuminate how risks of catastrophic climate change shape the mitigation-adaptation balance, and shed new light on how an international agreement committing all major emitters – or, equally importantly, the absence of such an agreement – affects the optimal balance between mitigation and adaptation.[1]

Chapter 3, *Boosting climate investment*, develops and applies a conceptual framework for analysing why there might be too little investment in mitigation and adaptation, and how to boost it. More specifically, the chapter identifies the most important of the multiple market failures and barriers that hinder climate investment, examines the policy instruments most suitable for removing such failures and barriers, and applies the failures/barriers-instrument framework to investment in low-carbon energy technologies, residential energy savings and private and public adaptation. While the quest for economic efficiency guides this analysis, it will pay attention to possible trade-offs between economic efficiency and environmental effectiveness. What is more, as this is not only a time of climate change, but also of exceptionally tight fiscal constraints, the analysis is mindful of the degree to which alternative policy instruments burden the public purse.

Chapter 4, *Green growth and green innovation*, widens the perspective by considering economic objectives that go beyond the narrow but important goal of cutting greenhouse-gas emissions – decarbonisation, for short. In particular, the chapter examines if decarbonisation reduces, increases or leaves unchanged economic growth – in the short and the long runs. To this end, the chapter describes the different channels that link decarbonisation and economic development. These include innovation, international competitiveness, terms-of-trade, public finance and aggregate capacity utilisation. In this context, the chapter examines to what extent it is welfare-enhancing to forgo economic growth in favour of decarbonisation. The chapter also analyses current EU climate policies and explores if and how they can be improved so that more growth and faster decarbonisation can be simultaneously achieved.

Each of these chapters is self-contained and can be read in isolation. That said, it is useful to provide some background to all of them. This is the purpose of the remainder of this introduction. The next section outlines the bare economics of climate change. Section 1.3 offers a glimpse at global and EU greenhouse-gas emission pathways – both for a continuation of current trends and action aimed at preventing dangerous anthropogenic interference in the climate system.[2] Section 1.4 gives an idea of how much EU countries need to invest in mitigating emissions if they want to deliver their contribution to the prevention of dangerous climate change. The goal of preventing dangerous climate change recognises that some degree of climate change is inevitable because of past greenhouse-gas emissions and the impossibility of stopping them immediately. Global warming is already underway, with global average temperatures estimated to have increased by 0.7°C to 0.8°C above pre-industrial levels (OECD, 2012). It follows that there is a need to adapt to a changing climate regardless of the challenge of properly balancing mitigation and adaptation. Estimates for adaptation-investment needs are less reliable than those for mitigation. Mindful of this, section 1.5 outlines the current information on EU adaptation investment needs. Section 1.6 offers a lead into the link between economic growth and the use of environmental resources – the atmosphere being one of them. Finally, section 1.7 concludes and links this chapter to those that follow.

1.2 The economics of climate change

Climate change raises profound public policy choices: what is the appropriate target level of greenhouse-gas concentrations in the atmosphere and by when should this target be met? How should the implied reduction in greenhouse-gas emissions be effectively and equitably delivered across different sectors of the economy, different countries and different generations? How should countries prepare for the inevitable residual climate change?

Economics can provide insights into the trade-offs faced by policymakers. Not surprisingly, economists' views on how to best tackle climate change vary widely – probably as widely as public opinion at large. This section draws on a rich literature to identify the key economic issues behind the differing positions on the speed and scale of the policy response: how much to mitigate and by when.[3] It leaves aside the question of how to deliver most effectively any given emissions-reduction target. This problem of instrument design is addressed in chapter 3.

The starting point of any discussion on the economics of climate change is to recognise the market failure at the core of the problem. The Stern Review (2007) makes this point strikingly: "*Greenhouse gas emissions are externalities and represent the biggest market failure the world has seen*." The failure is clear: greenhouse-gas emissions cause global warming and hence impose costs on society – this and subsequent generations. If the market is left to itself, these emissions are in effect treated as free by individuals when choosing what to consume or produce, which distorts decisions towards a relatively carbon-intensive pattern of economic activity. Put differently, in the absence of government intervention, economic activity results in excessive greenhouse-gas emissions.

This concept of an externality is an old one in economics, developed in the early twentieth century so that conditions under which markets might fail – that is, result in an outcome that is not optimal for society as a whole – could be understood. However, climate change is not a standard, local externality. It has some distinctive features shaped by the underlying science.

It is instructive to highlight the key steps within the externality chain. Much economic activity results in emissions of greenhouse gases. These emissions increase the stock of greenhouse gases in the atmosphere which, in turn, traps heat and results in global warming. Global warming results in climate change, with impacts on people, species and plants in complex ways, most notably via water in some form (storms, floods, droughts, sea-level rise). Each link in this chain involves considerable uncertainty and long time lags.

As stressed by Stern, climate change is a distinctive externality in four ways: (i) it is global in its origins and impacts: it is the stock of greenhouse gases that matters, not the origin of the emissions; (ii) some of the effects are very long term (that is, over centuries) and will therefore only impact future generations; (iii) there is a great deal of uncertainty inherent in most steps of the scientific chain; and (iv) the effects are potentially very large, abrupt and irreversible. These features shape the underlying economics of the policy response.

The remainder of this section is devoted to illustrating the influence two distinctive features – long time lags and pervasive uncertainty – can have on the optimal speed and scale of global emission cuts.

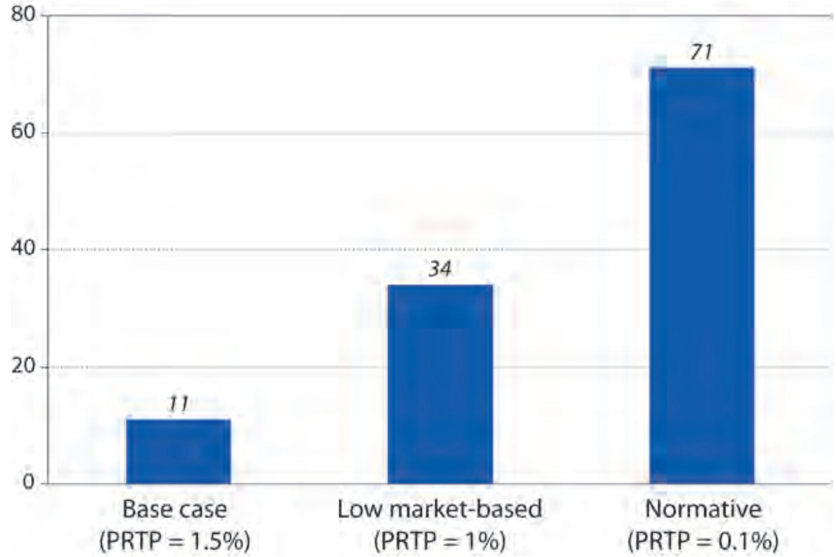
First, consider the long time lags involved. Mitigation policy involves costs now to cut greenhouse-gas emission and, thus, secure benefits around the globe long into the future. In order to compare costs and benefits accruing at different points in time, economists traditionally apply a social discount rate. Adopting a high discount rate – in effect reducing the net present value of long-term benefits compared to near-term costs – results in recommending relatively modest short-term emission reductions. Conversely, lowering the discount rate implies deeper and earlier cuts.

This rather technocratic-sounding discussion turns out to matter a great deal. Using multi-disciplinary models, known as integrated assessment models, researchers have attempted to estimate the damage from emitting one tonne of greenhouse gas. Based on a well-known model – pioneered by Nordhaus and Boyer (2000) – Figure 1 shows how three different sets of assumptions on the discount rate can have a dramatic impact on the estimation of the damage from emitting a tonne of carbon dioxide (CO_2).

The column on the left-hand side shows the results of applying a market discount rate – considered the base case in Nordhaus (2011a). One tonne of CO_2 is estimated to impose a cost of €11. In this case, investments today to abate carbon are worthwhile if they cut emissions at a cost of less than €11/tCO_2. By contrast, the column on the right-hand side shows results from the same model but instead takes a normative approach to one important parameter (the so-called pure rate of time preference) influencing the discount rate, as advocated in the Stern Review. Investments up to €71/tCO_2 would be justified. So what is the correct value?

This is not the place for a lengthy discussion of the determinants of the social discount rate.[4] However, based on the well-known Ramsey equation from optimal economic growth, the discount rate can be shown to depend, among other things, on an unobservable ethical parameter – the pure rate of

Figure 1: Damage from greenhouse-gas emissions under different discount rates (in €/tCO_2)



Source: Nordhaus (2011a); authors' adjustment to convert to 2010 euros, rounded to avoid spurious accuracy.
Notes: Estimated for emissions in 2015. PRTP = pure rate of time preference.

time preference (PRTP). This captures the relative weight of the economic welfare of different generations over time – an ethical judgement. Stern argues forcefully that the welfare of different generations should have equal weight, that is, the PRTP is (close to) zero. This is the case pictured by the column on the right-hand side of Figure 1.

By contrast, Nordhaus takes a positive rather than normative approach and simply calibrates the overall discount rate to be consistent with observed returns to capital. This is the case in the column on the left-hand side of Figure 1, which assumes a market discount rate equal to just over 5 percent, which – in turn – implies a value for the PRTP equal to 1.5 percent. The middle column shows the impact of dropping the PTRP to 1 percent, equivalent to a low but justifiable market discount rate of just over 4 percent.

This difference in approach – the normative approach of Stern versus the positive approach of Nordhaus – has been recognised in the economics literature since the earliest papers on economic growth. The science of climate change, however, has moved this issue from a dormant backwater of growth theory into the centre stage of public policy on climate change. In conclusion, given the long time lags involved, the policy recommendations made regarding the urgency and depth of emission reduction often depend, implicitly or explicitly, on the ethical viewpoint taken on equity between generations – as reflected in the pure rate of time preference.

The second distinctive feature that can have a strong bearing on policy recommendations is the considerable uncertainty surrounding each step in the chain translating emissions into global warming and damages. Indeed, the way in which uncertainty is conceived and modelled can play an important role in shaping the policy response advocated by economists.

In terms of formal models, such as the integrated assessment models presented above, uncertainty is usually introduced by adding results under different states of the world, weighted by the probability of those states. In the case of climate change, these probabilities are usually simply 'best guesses', derived from the state-of-the-art of the natural sciences and economics. Under standard assumptions, this approach justifies paying additional abatement costs today (the insurance premium) to reduce the risks of an uncertain future.

As reviewed in detail by Nordhaus (2011a, 2011b), most climate modellers have introduced uncertainty in a rather simplistic way within a normal probability density function, thus assuming that possible climate change impacts distribute symmetrically around their mean, with 'thin tails' of the function suggesting a reasonably fast declining probability of either negligible (even positive) or severe (possibly catastrophic) climate impacts.

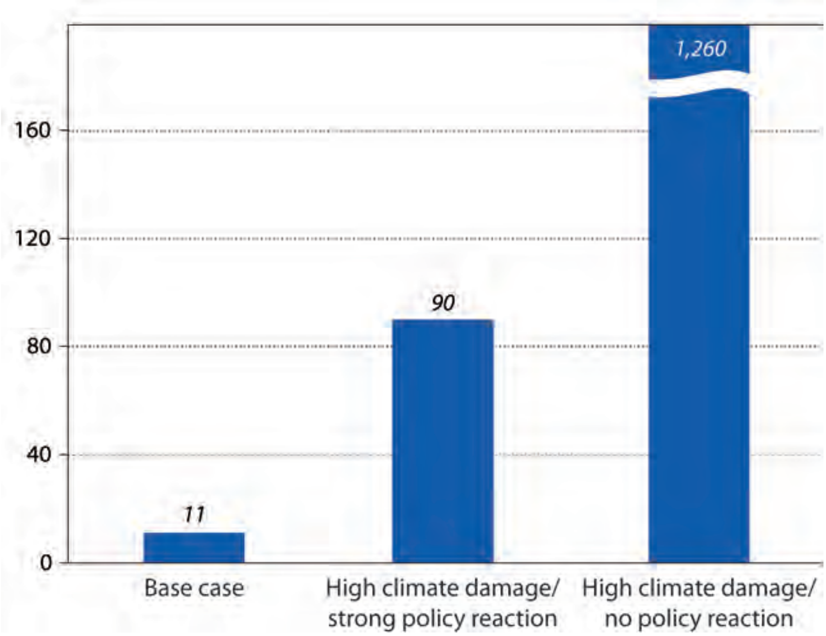
This approach strikes many as unsatisfactory given the potential for global warming to trigger abrupt, large-scale and irreversible changes in the climate system. Examples include the possible disruption of the Gulf Stream and the collapse of the West Antarctic ice sheets. Arguably, the *ex-ante* probability of these events can be more usefully modelled as a skewed, fat-tailed distribution, implying that the probability of severe climate impacts does not fall as rapidly as it would under a symmetric, thin-tailed normal distribution. Weitzman (2009) has considered the implication for economic policy of using such distributions. He comes to a dramatically different conclusion to standard analyses of uncertainty, summarised in his so-called dismal theorem. In the extreme case, a combination of fat tails, unlimited exposure to severe climate impacts and high risk aversion implies that the expected climate change damage is infinite and, thus, standard cost-benefit analysis ceases to be a meaningful analytical tool.

As with the case of modelling discount rates, relatively technocratic-sounding discussions about key model parameters (or shapes of distributions) can lead to dramatically different policy conclusions. In the case of catastrophic climate events, it is very hard – if not impossible – to know what the 'correct' probability distribution is likely to be.

Interesting work has been done to illustrate the potential impact of high-damage climate events. Ackerman *et al.* (2010) show that if both the impact of greenhouse-gas concentrations on global temperatures is much higher and the damage function linking temperatures and climate damages much steeper than generally assumed, the overall impact on the economy is sustained and deep, possibly catastrophic. This approach has been further generalised in Nordhaus (2011b). Figure 2 shows some illustrative results of the damage per tonne of carbon dioxide.

The column on the left-hand side repeats the base-case result from Figure 1: a tonne of carbon dioxide results in damages of €11. In the second column, two key model parameters take extreme values,[5] but policy is able to react immediately by making deep emissions cuts once extreme parameter values materialise. In this case, the expected damage equals €90/tCO_2. This is a sizeable increase, but it does not constitute a catastrophic event for the economy, implying a decline in welfare of about 2 percent on 2005 levels. The third column, by contrast, assumes that global governments are unable to react to the discovery of high-damage climate parameters. In this case, the impact on the economy is truly catastrophic, imposing a damage of €1,260, equivalent to a 95 percent loss in welfare. Probably not too much attention should be paid to the numerical results. It is more useful to interpret this as a set of conditions consistent with Weitzman's dismal theorem – that is, the insight that even incredibly unlikely catastrophic events might imply

Figure 2: Damage from greenhouse-gas emissions under different climate change impacts and policy reactions (in €/tCO_2)



Source: Nordhaus (2011a): authors' adjustment to convert to 2010 euros, rounded to avoid spurious accuracy.
Note: Estimated for emissions in 2015.

infinitely large expected losses for society. It also underlines the importance of a decisive, quick international policy response if and when natural sciences point to climate change impacts far worse than currently expected.

All in all, the approach taken towards uncertainty can have a significant role in determining climate policy recommendations. Under the approach adopted by many economists so far, relatively minor policy implications arise from the introduction of uncertainty. At the other extreme, different assumptions might suggest infinite losses, suggesting that greenhouse-gas emissions should be cut rapidly and vigorously.

To conclude, this section has explored some central economic aspects of climate change. The key insight is that greenhouse-gas emissions are an externality and there is, thus, a market failure. Two key factors determine the size of this market failure and, thus, how vigorous policies should be in addressing it. The first is the social discount rate, which captures an ethical judgement about the distribution of costs and benefits between this generation and future generations. Arguably, the key legacy of the Stern Review is to remind the world forcefully that ethical issues are fundamental to the economic response. The second factor is uncertainty and, in particular, how economic assessments account for low-probability, high-damage events.

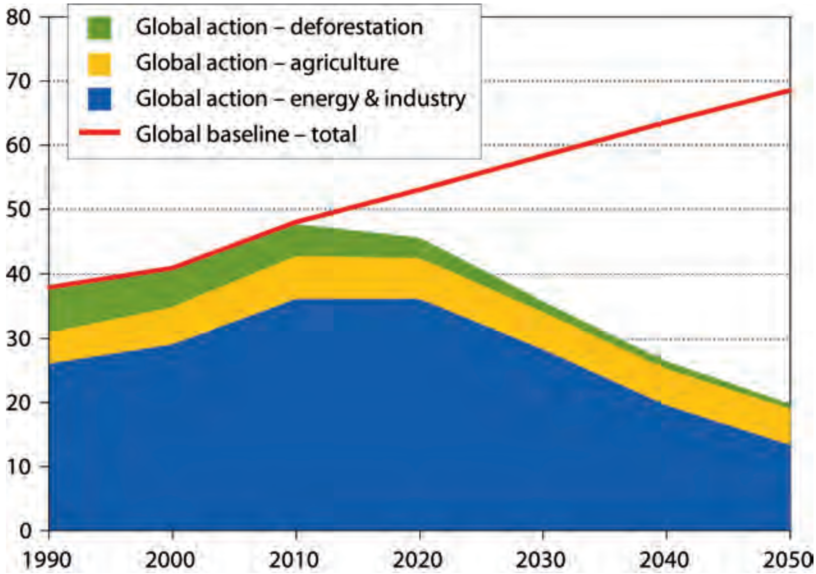
At a more pragmatic level, governments need to act to meet agreed emissions-reduction targets and to deal with the prospect of future climate change, regardless of whether the targets are perfect. This raises the issue of finding the right policy mix, confronted with a sometimes bewildering array of potential market failures. This topic – giving rise to a large body of applied economic analysis – is picked up in the chapters that follow.

1.3 Greenhouse-gas emission pathways

Future global greenhouse-gas emissions depend on a myriad of interdependent parameters, notably population and GDP growth, energy prices, technological progress and the climate action the world community takes. As these parameters can have many values, possible greenhouse-gas emission pathways abound. Drawing on European Commission (2011a), Figure 3 pictures two of them for all greenhouse gases – mainly carbon dioxide (CO_2).[6] One pathway is called global baseline. It assumes a continuation of current trends and projects emissions in the absence of new policies beyond those already in place. Under this scenario, the global average temperature at the end of this century is likely to be 3°C to 6°C higher than in pre-industrial times (OECD, 2012). The other pathway is labelled global action. It assumes that the world embarks on action to cut emissions so that there is a 50-percent chance of keeping the temperature increase to 2°C.

Under baseline assumptions, annual global greenhouse-gas emissions are projected to increase from about 48 gigatonnes (Gt) of CO_2-equivalent in

Figure 3: Global greenhouse-gas emissions (in gigatonnes of CO_2 equivalent) – baseline scenario vs. action scenario, 1990-2050



Source: European Commission (2011a).

2010 to almost 70Gt by 2050. By contrast, the global-action pathway envisages a cut in emissions of 28Gt by 2050, which is about 71 percent below baseline emissions. Relative to 1990 – that is, the Kyoto Protocol benchmark – this would be a cut of almost 50 percent. For the global-action pathway, Figure 3 also illustrates how various emission sources (deforestation and forest degradation, agriculture, and energy use/transformation and industry) are expected to develop over time and, by extension, how much they contribute to the total emissions cut. In absolute terms, emissions from energy and industry are projected to fall the most. Emissions from deforestation are envisaged to almost disappear whereas emissions from agriculture are foreseen to increase by about 1Gt relative to 1990.

Figure 3 makes it easy to see the difference between both pathways and, thus, the challenge if the 2°C target is to be reached. An equally telling way to grasp the challenge is to consider the greenhouse-gas emissions budget mankind has available to it if it wants to meet the 2°C target. Tavoni *et al.* (2012) reckon that future cumulative emissions should not exceed 2,000 $GtCO_2$ if the aim is to meet the 2°C-target with a probability of 50 percent. They also estimate that greater confidence in meeting the target (probability of 95 percent) leaves an emission budget of only 1,000 $GtCO_2$. While these figures are not directly comparable to the data in Figure 3, they nonetheless provide an informative perspective. Under the baseline path shown in Figure 3, an emission budget of 1,000 and 2,000 Gt would be exhausted in 2030 and 2045, respectively. Under global action, an emission budget of 2,000 Gt would last beyond 2050, but a budget of 1,000 Gt would be fully used by 2040. Tavoni *et al.* (2012) also point out that developing countries require a budget of 2,000 Gt to catch up with living standards in richer parts of the world. This would leave no emission budget for developed countries for a global limit of 2,000 Gt and it would require negative emissions – that is, sequestration of greenhouse gases – of 1,000 Gt for a global limit budget of 1,000 Gt.[7]

Presenting and discussing the two greenhouse-gas emission pathways illustrates the scale of the challenge. That said, it is worth considering a few qualifications – some of which suggest that the challenge is even more daunting, while others enable the opposite conclusion to be drawn. For a start, there is the view that the temperature limit compatible with a safe climate future is not 2°C but 1.5°C – if not less. Small island states, for instance, have long held this view, and prominent climate change negotiators share it.[8] All other things being equal, global action would have to be more ambitious than the path shown in Figure 3.

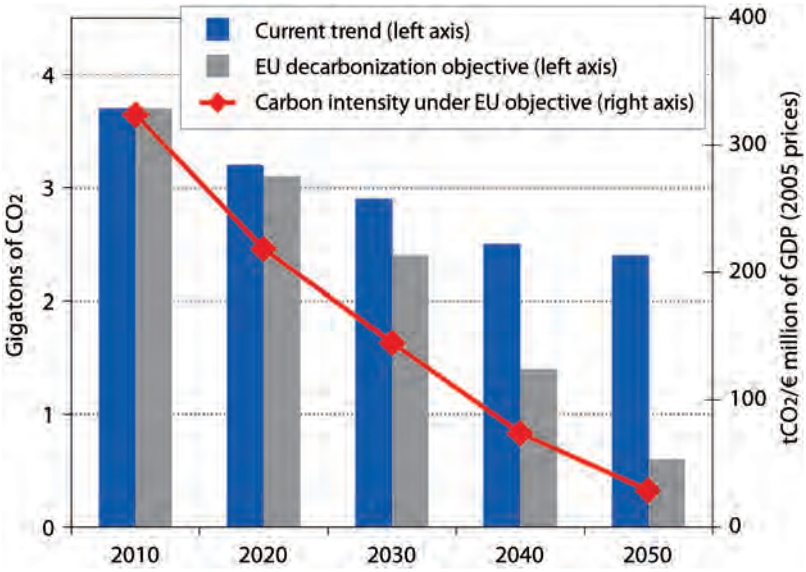
Furthermore, the global-action pathway is typically understood as offering a 50 percent chance of limiting the temperature increase to 2°C. Greater cuts would be needed if the aim is to remain below 2°C with a greater probability. Indeed, as the work of Tavoni *et al.* (2012) illustrates, the required cuts might increase considerably if the world community wants to have greater confidence in meeting the target.

Finally, the world community has established the 2°C target as a political target based on scientific evidence. Thus, policymakers implicitly find that the benefits of keeping the rise in global temperature below 2°C outweigh the cost of doing so (OECD, 2012). Notwithstanding political agreement on the 2°C target, climate-change economists continue to debate its cost-benefit balance. Whether or not it is appropriate from an economic-efficiency viewpoint largely depends on which discount rate is used and how uncertainty and possible catastrophes are accounted for – as explained in the previous section. For instance, accounting for the costs and benefits of cutting greenhouse-gas emissions, Nordhaus (2011b) finds efforts to limit the rise in temperature to less than 2.8°C to be welfare reducing. As a result, while he argues for cutting emissions below baseline and current levels, the cut he finds optimal is not as big as under the global-action pathway of Figure 3.

It is useful to zoom in on the European dimension of climate action. EU member states have committed to reduce, by 2020, their greenhouse-gas emissions by 20 percent relative to 1990, and they are willing to move to 30 percent as part of a genuine global effort. Looking beyond 2020 and bearing in mind the 2°C target, the EU has set the objective, in the context of necessary reductions that should be made by developed countries as a group, according to the Intergovernmental Panel on Climate Change (IPCC), of reducing greenhouse-gas emissions by 80-95 percent by 2050 compared to 1990.[9] On current trends, the 20-percent commitment for 2020 will be achieved whereas EU emissions in 2050 would end up 40 percent rather than 80-95 percent below emissions in 1990.

Focusing on energy-related carbon dioxide emissions rather than total EU greenhouse-gas emissions, Figure 4 illustrates the degree of decarbonisation associated with the 2050 climate objectives. Before discussing what the figure shows, it is useful to note that energy-related emissions (which presently account for almost 80 percent of EU greenhouse-gas emissions) cover the energy sector, transport, industry and households. On current trends, these emissions are anticipated to fall from 3.7 $GtCO_2$ in 2010 to 2.4 $GtCO_2$ by 2050. Compared to 1990, this would be a 40 percent cut. By contrast, decarbonisation in line with EU objectives calls for a reduction to about 0.7 $GtCO_2$ by 2050, implying a cut of about 85 percent relative to 1990. The line in Figure 4 indicates that the carbon intensity of the EU economy is envisaged to drop by an impressive 90 percent during 2011-50, with carbon intensity measured in tonnes of emissions per €1 million of GDP.

Figure 4: EU energy-related CO_2 emissions (in gigatonnes of CO_2) – current trend vs. EU objectives, 2010-50



Source: European Commission (2011d).

In its *Energy Roadmap 2050*, the European Commission explores different scenarios for meeting the decarbonisation objective pictured in Figure 4 (European Commission, 2011c, 2011d). Obviously, at the end of the scenario horizon, all scenarios are meant to achieve the same degree of decarbonisation. In fact, even the time profile of emission cuts is very similar across scenarios. Scenarios differ, however, in the relative contribution they assign to energy savings, renewable energy, nuclear energy and carbon capture and storage, respectively. As a result, scenarios differ in the type and size of investment needed for decarbonising the EU economy. This will be addressed next.

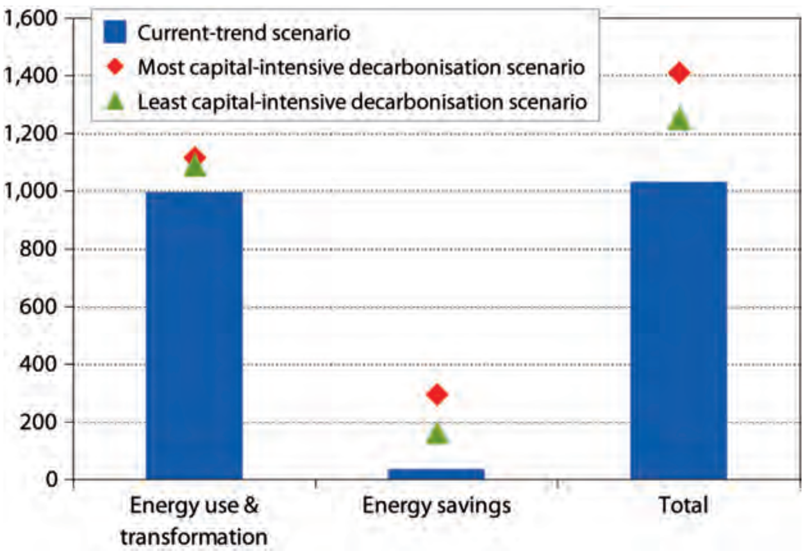
1.4 Mitigation investment needs in a decarbonising world

Before presenting monetary estimates of investment needs in a decarbonising world, it makes sense to stress two salient features of such estimates. First, they inevitably rest on assumptions. A crucial assumption concerns unit capital costs. Obviously, for a given greenhouse-gas emission pathway, estimated investment needs become higher, the higher the capital costs. Second, estimates very much depend on the boundaries of the analysis. Most obviously, they are higher, the greater the geographical coverage of the analysis, which could range from a single country to the whole world. Estimated investment needs are also higher, the more greenhouse gases the analysis includes – the range here could be from carbon dioxide emissions of one particular sector to all greenhouse gases of all sectors. Finally, estimates will be higher for investment not only directly aimed at greenhouse-gas mitigation but also related to research and development efforts and investment in upstream activities – such as developing better engines, fuel cells and insulation materials.

In what follows, the focus is on investment directly aimed at bringing about the cut in energy-related EU carbon dioxide emissions as pictured by the columns labelled 'EU decarbonisation' in Figure 4. Estimates are taken from European Commission (2011d),[10] but the presentation here is deliberately condensed. Two broad types of investment are distinguished: first, investment related to the use and transformation of energy, such as capital expenditure on power plants and energy infrastructure, energy-using equipment and appliances, and vehicles; and second, investment in energy savings, such as expenditure on better house insulation, energy control systems and energy management.[11]

Considering the period 2011-50, Figure 5 shows, for the EU, average annual expenditures on both types of investment. The columns represent investment for a current-trend scenario, that is, a future without policies other than those in place in 2011. Under this scenario, energy-related carbon dioxide emissions in 2050 would only be about 40 percent lower than in 1990. The triangle and diamond in Figure 5 show, respectively, investment for the least capital-intensive and the most capital-intensive decarbonisation scenarios presented in European Commission (2011d). The most capital-intensive decarbonisation scenario rests more than other scenarios on energy savings. It is important to bear in mind that all decarbonisation scenarios – regardless of their capital intensity – would make emissions in 2050 about 85 percent lower than in 1990. Equally important, European Commission (2011d) argues that all decarbonisation scenarios involve very similar total energy-system costs, which implies that the extra investment cost of a relatively capital-intensive decarbonisation pathway is compensated for by additional energy-cost savings.

Figure 5: Average annual EU investment in current-trend scenario and alternative decarbonisation scenarios in 2011-50 (€ billions, 2008 prices)



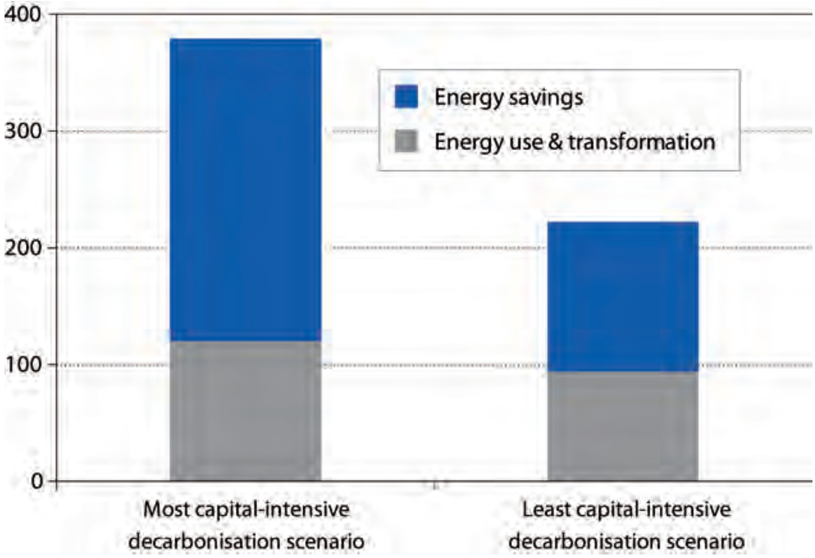
Source: Own presentation based on European Commission (2011d).

The main message from Figure 5 is that the total annual investment on a decarbonisation pathway is projected to range from €1,250 billion to €1,410 billion. This compares to a figure of about €1,030 billion for the current-trend scenario. Thus, additional investment of €220 billion to €380 billion per year is needed to move the EU economy to a path that doubles emission reductions. Are these big numbers? To get a rough feel, one can relate them to the average annual GDP underlying the scenarios in European Commission (2011d), which is about €18,000 billion in 2008 prices. Additional investment then equals 1.2 to 2.1 percent of GDP.[12]

Figure 6 examines the additional investment needs. It highlights that investment directly aimed at energy savings is projected to account for some

60-70 percent of the additional investment needed to accelerate the decarbonisation of the EU economy. It also shows that the difference between the most and the least capital-intensive scenarios is almost entirely due to investment in energy savings. This reveals that the most capital-intensive decarbonisation path is the one that envisages a greater role for energy savings than alternative scenarios, which rely more on renewables, carbon capture and storage or nuclear energy.

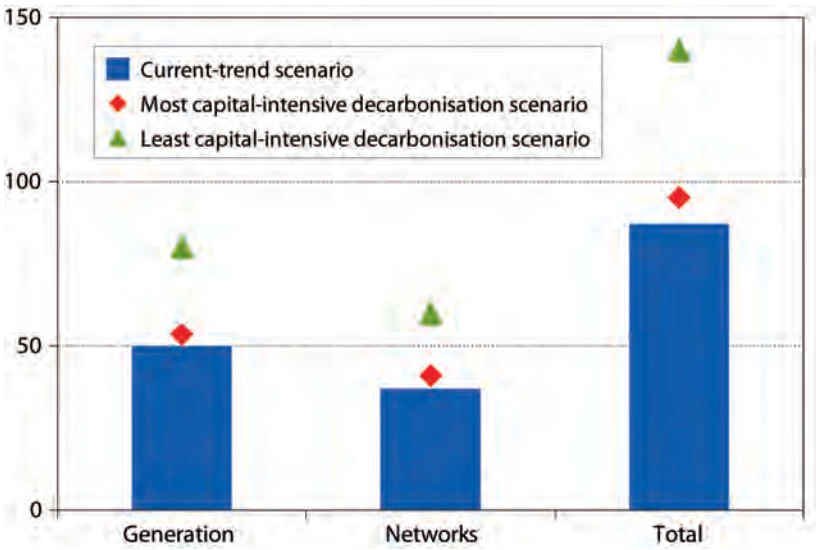
Figure 6: Additional average annual EU investment needs under alternative decarbonisation scenarios in 2011-50 (€ billions, 2008 prices)



Source: Own presentation based on European Commission (2011d).

Finally, it is illustrative to zoom in on power-sector investment, which is one component of investment in energy use and transformation. For the current-trend scenario, Figure 7 indicates average annual power-sector investment of about €85 billion. This figure goes up to €140 billion for the least capital-intensive decarbonisation scenario, which is the one relying more than other scenarios on investment in renewable electricity. For the most capital-intensive decarbonisation scenario, which rests more than other scenarios on energy savings, investment needs are estimated at €95 billion. It is not a contradiction that the least capital-intensive decarbonisation scenario requires more power-sector investment than the most capital-intensive. The investment shown in Figure 7 is for the power sector alone, while the distinction between different decarbonisation scenarios reflects their overall capital intensity. In fact, the apparent contradiction brings to the fore that, compared to all other pathways, the most capital-intensive (which emphasises energy savings more than other pathways) requires additional investment in energy savings that are much bigger than the investment in energy use and transformation avoided because of a greater emphasis on energy savings.

Figure 7: Average annual EU power-sector investment needs for current-trend scenario and alternative decarbonisation scenarios in 2011-50 (€ billions, 2008 prices)



Source: Own presentation based on European Commission (2011d).

To conclude, the investment needed to get the EU economy onto a low-carbon trajectory is sizeable. Specifically, extra investment of up to €380 billion a year is required – an increase of 30-40 percent relative to current trends. Investment in energy savings is envisaged to account for more than half of the extra investment. Whether the extra investment materialises depends on whether it is, or can be made, profitable – an issue at the heart of chapter 3.

1.5 The inevitable need for adaptation – come high or low water

According to the IPCC (2007), average global temperature will increase by about 0.6°C to 1.0°C even if the concentration of greenhouse gases in the atmosphere could remain at the level in 2000. As the concentration has increased since then and is bound to increase further, some climate change is programmed to happen. Hence, some adaptation seems inevitable.

The challenge of adapting to climate change is much bigger for developing than developed countries. Developing countries are often more exposed to climate change impacts and their capacity to adapt is typically low. This combination makes them very vulnerable to climate change. Consequently, the literature has mainly focused on adaptation in developing countries (see World Bank, 2010; UNFCCC, 2007; Oxfam, 2007). This report takes a European perspective, however. It argues that although EU countries are less vulnerable than many other countries, they are far from immune to a changing climate and, thus, need to worry about how to effectively adapt to it.

Broadly defined, adaptation is any measure that changes the costs or benefits from climate change. Adaptation may come in many different forms. The range is enormous, from changing planting dates of agricultural crops to undertaking large infrastructure projects such as coastal protection systems.

Studies such as that of Konrad and Thum (2012) classify adaptation according to a number of variables, not all of which are necessarily relevant for the purposes of this report. Four adaptation variables are of special interest. First, depending on whether or not an adaptation measure has public-good characteristics, it may be undertaken privately by households and businesses or it may be provided by the state. Second, depending on their timing relative to climate-change impacts, adaptation measures may be in response to impacts that have occurred and are therefore reactive. Alternatively, they may come in anticipation of impacts, in which case they are anticipatory (or proactive). Third, adaptation measures may accumulate as stocks (following on from investment), such as storm-surge barriers, but they can also come as current spending flows, such as the operating cost of existing air conditioners. Finally, some adaptation might be geared towards enhancing the climate resilience of new or existing physical assets – residential property, factories, infrastructure and so on – while other kinds of adaptation are dedicated to coping with changes in climate – dykes being the most obvious example.

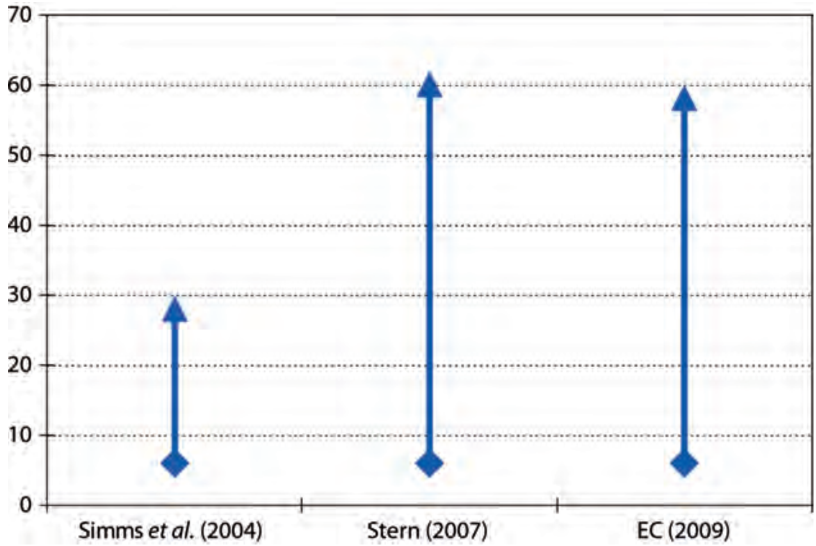
In the first half of this century climate change is expected to manifest itself mostly through more frequent extreme weather events. While adaptation measures will be needed to address them, the bulk of adaptation expenditure is expected in the second half of the century when climate change impacts intensify. This long time horizon and the associated uncertainty substantially complicate the task of estimating adaptation investment needs. Nevertheless, the literature on this topic continues to grow, spurred by its importance for policymaking. Fankhauser (2009, 2010) divides studies in this field into first and second generations.

The first-generation estimates follow a top-down approach and are mostly based on a method used by the World Bank (2006). The method consists of estimating current financial flows, such as development aid, foreign direct investment and gross domestic investment, and then applying a mark-up that is based on the assumed climate sensitivity and costs of making investments climate resilient. The assumption on the size of this mark-up is often somewhat arbitrary and has little rigorous empirical grounding. The top-down approach is used by a number of studies, such as Stern (2007), Oxfam (2007) and UNDP (2007).

Figure 8 presents estimates of adaptation investment needs from three studies that provide estimates for EU countries: Simms *et al.* (2004), Stern (2007), and European Commission (2009). As Figure 8 shows, the range of estimates is wide and varies significantly across studies. This variation is closely linked to the assumed size of the mark-up necessary to make investment climate resilient.

Overall, in addition to this mark-up sensitivity, first-generation estimates of adaptation investment needs lack empirical support and an explicit analysis

Figure 8: First-generation adaptation investment estimates for Europe ($ billions per year)



Source: Springmann (2012).

Notes: Sectoral coverage is limited to the construction sector; no explicit time-horizon is considered. Simms *et al.* (2004) assume that 1-5 percent of current buildings costs is needed to make new infrastructure climate resilient; Stern (2007) assumes 1-10 percent, as does European Commission (2009).

of adaptation options. Hence, they are not more than an educated guess – an informative one nonetheless.

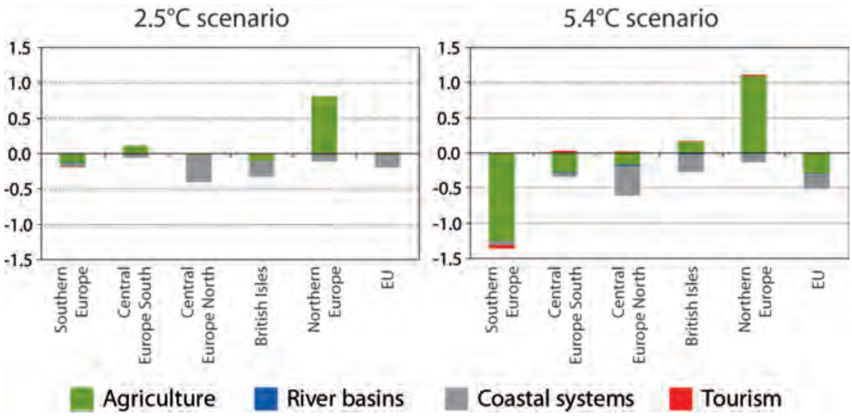
Second-generation estimates are based on a bottom-up methodology and take into account responses to climate change impacts in various sectors. Studies using this methodology are much more diverse. They differ in the climate and socio-economic scenarios assumed, the time horizon considered and the explicit representation of adaptation options.

There are three well-known and widely cited second-generation studies: UNFCCC (2007), World Bank (2010) and PESETA (2009). The first two focus on developing countries and pay little or no explicit attention to EU countries. By contrast, PESETA (2009) focuses exclusively on EU countries. It estimates the physical and economic consequences of climate change by sector and region, while taking into account private adaptation strategies. Strictly speaking, the study does not estimate investment needs to adapt to climate change in the EU and it does not provide a complete economic analysis of adaptation. Rather, its estimates indicate potential economic impacts in the absence of broadly planned adaptation. From an economic perspective, these estimates can be viewed as an upper bound on adaptation investment because it would not make sense to spend more on avoiding climate change impacts than the cost of enduring them.

PESETA (2009) provides estimates of climate impacts in five impact categories: agriculture, river floods, coastal systems, tourism and human health. These estimates, health excluded, are fed into a model of the whole European economy that accounts for the direct and indirect effects of these impacts.[13] The results indicate that climate-change related output losses in the EU would amount to €22-67 billion (equivalent to about 0.2-0.5 percent of GDP), depending on the extent of climate change.[14] As the climate-change vulnerability differs across EU countries, however, economic losses are not distributed evenly across the EU. Figure 9 plots the GDP impact in different European regions and the contribution of each of the four areas to this impact for two temperature scenarios: 2.5°C warming and 5.4°C with high sea-level rise. Depending on the scenario, southern Europe, central Europe north and the British Isles are set to experience the largest losses, albeit for different reasons. In southern Europe, the largest impact comes from agriculture, particularly in the high-temperature scenario, followed by coastal systems. Central Europe north is affected mostly by coastal-system impacts and losses are exacerbated by the agricultural sector for the high-temperature scenario. The British Isles suffer mostly due to impacts on coastal systems and river basins, while tourism and agriculture might actually benefit from climate change depending on the climate-change scenario. Northern Europe is the sole net winner from climate change mostly due to agriculture.

The methodology used to calculate the economy-wide estimates has been subject to substantial criticism, and results, though illustrative, should be interpreted with care.[15] By contrast, estimates of direct, sectoral impacts in PESETA (2009) are of higher quality as they are based on careful physical impact studies of regions and sectors. For three sectors, Figure 10 offers a comparison between economy-wide results from general-equilibrium modelling and direct estimates obtained from sector analyses. It illustrates

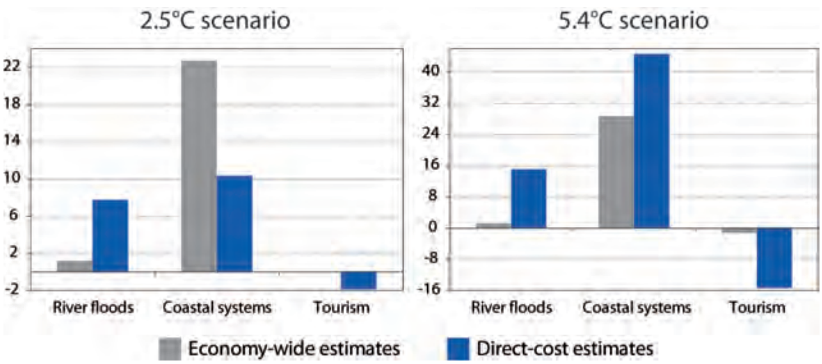
Figure 9: GDP impact (in percent) for 2.5°C and 5.4°C warming scenarios



Source: Ciscar *et al.* (2011)
Note: There are two 5.4°C warming scenarios – one for a low sea-level rise and another for a high sea-level rise. Estimates shown here are for the high sea-level rise.

that economy-wide impacts can hide major impacts obtained from sector studies, with direct estimates being higher than economy-wide estimates – except for coastal-system costs in the 2.5°C scenario.

Figure 10: Climate change impacts – economy-wide vs. direct estimates (in € billions)



Source: Springmann (2012)
Note: The 5.4°C warming scenario is for low sea-level rise.

In summary, methodologies for estimating climate impacts are far from perfect and estimates continue to be approximate. Nonetheless, they give an idea of the resources required to prepare Europe for a warming world. Methodologies have progressively improved and further improvement is expected as the literature on the topic advances.

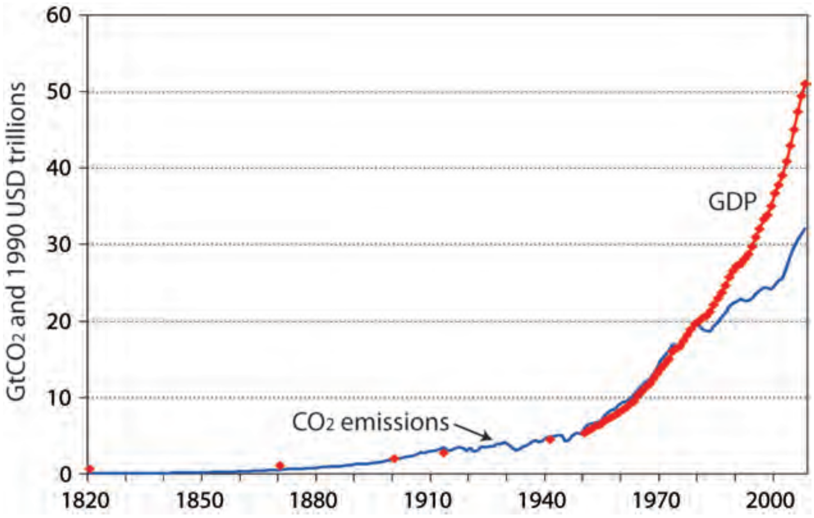
1.6 Economic growth and the environment

Over the past 200 years, economic growth has been inherently linked to energy consumption and greenhouse-gas emissions. Figure 11 plots estimates of world GDP and CO_2 emissions since 1820. Evidently, exponential economic growth was accompanied by a commensurate increase in greenhouse-gas emissions from burning fossil fuels. It is also worth noting that world population has grown eightfold since 1820 and it is expected to reach 9 billion by 2050, which is 1.3 times that of today.

Obviously, the world cannot afford an increase in greenhouse-gas emissions in line with historic patterns. In fact, as illustrated in section 3, emissions will have to decline substantially and permanently to limit the rise in global temperature to no more than 2°C. In light of the historic link between economic activity and greenhouse-gas emissions, this will be possible only if world output declines substantially and permanently or economic growth decouples from greenhouse-gas emissions.

Decoupling of greenhouse-gas emissions from output means that carbon intensity, defined as emissions per unit of output, will have to decline. Global carbon intensity has indeed decreased since 1980 – as Figure 11 indicates. According to Jackson (2009), it fell from 1,000 grammes of CO_2 equivalent per US dollar of output in 1980 to 768 grammes in 2007, which constitutes an annual rate of decline of 0.7 percent. However, even if carbon intensity were to continue to fall at this rate, it would not even dent the projected increase in global emissions. Assuming GDP growth continues in line with current trends and population reaches 9 billion by 2050, carbon intensity would need to fall at an annual rate of 8 percent to meet the 2°C target. Such a reduction is a tall order even for the most technologically advanced countries. To illustrate the scope of the challenge, McKinsey Global Institute (2008) compares the necessary decline in carbon intensity with labour productivity growth during the industrial revolution. According to this study, the world

Figure 11: World GDP and global CO_2 emissions



Source: Carbon Dioxide Information Analysis Center (http://cdiac.ornl.gov/ftp/ndp030/global.1751_2008.ems) and Maddison world GDP estimates (http://www.theworldeconomy.org).

Notes: Emissions are from fossil fuel burning, cement manufacturing and gas flaring. They are shown in gigatons of CO_2. GDP in trillion USD, 1990 prices.

has about 40 years to achieve a reduction in carbon intensity of a similar magnitude as the increase in labour productivity in the United States between 1830 and 1955.

Given the aspirations of much of the world's growing population to catch up with higher living standards elsewhere in the world, the key question, then, is if it is possible to sever the link between economic growth and greenhouse-gas emissions. Chapter 4 will examine this question in greater detail. Here, a few pointers can be given from a selection of academic studies. For a start, Stokey (1998) studies the relationship between per-capita income and environmental quality. A key point is the observation that environmental regulation increases as society gets richer while more regulation decreases the rate of return on capital. In fact, very rigorous environmental regulation might result in a rate of return that is so low that investment and growth decline. Whether society embarks on an unrelenting path of economic growth or one where growth ceases ultimately depends on how society values material well-being relative to environmental quality. The good news is that good policy design allows society to safeguard environmental quality up to a point and sustain economic growth at the same time.

In a similar vein, Jones (2009) notes the importance of weighing the benefits of economic growth against its costs: pollution, nuclear accidents, global warming and other dangers stemming from unchecked technological change. He shows that accounting for these costs may have severe consequences for growth. In his framework, technological progress drives economic growth but also bears a small probability of producing a deadly disaster. Jones finds that if society attaches greater value to increasing the probability of its survival than to consumption growth, it chooses safety over economic growth thereby reducing innovations. Consequently, economies will grow more slowly and growth may even come to a complete stop.

Finally, Acemoglu *et al.* (2012) study how endogenous and directed technological change interacts with environmental constraints in a model of growth. Distinguishing between a 'dirty' and a 'clean' sector of production, they find that economic policies can avoid environmental disaster if the output of the clean sector is a sufficiently good substitute for the output of the dirty sector. This is the case, for instance, when replacing fossil fuel-based electricity with (near) zero-carbon electricity. However, the transition to clean growth is not without cost. Growth slows down during the period when policies redirect innovation to the clean sector of the economy. Moreover, this period of slower growth is longer the more policies are delayed. If the clean output is a less good substitute for the dirty one, environmental disaster can still be avoided, but it requires a permanent rather than merely transitory redirection of innovation efforts, and economic growth might be subdued for good.

All in all, the challenge of cutting global greenhouse-gas emissions while maintaining economic growth is formidable – requiring a decoupling of growth from emissions far more comprehensive than the decoupling observed since the beginning of the 1980s. That said, current economic research suggests that severing the link between growth and emissions is possible, but it requires appropriate policy action.

1.7 Summary

The purpose of this introductory chapter has been threefold. First, we have set out the boundaries of this report on *Investment and growth in the time of climate change* and emphasised that it covers just one of many challenges that climate change poses. Second, we have illustrated how drastic a decline in greenhouse-gas emissions, how radical a departure from the historic link between economic growth and emissions, and how big an investment boost are needed to meet the internationally agreed goal of limiting the increase in global temperature to no more than 2°C compared to pre-industrial times. Third, the purpose has been to introduce key economic aspects shaping the climate policy response, including the externality of greenhouse-gas emissions, the public-good nature of cutting them, and the role of discounting and uncertainty in determining how rapidly and vigorously mankind should break with the past. These aspects and others will feature prominently in the chapters that follow, starting with the quest for an optimal balance between climate-change mitigation and adaptation (chapter 2), ways and means of boosting climate investment (chapter 3) and growth- and innovation-friendly climate action (chapter 4).

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CHAPTER 2

Mitigate, adapt or endure: A question of balance

Atanas Kolev

Chapter at a glance

This chapter discusses the role of economic trade-offs in designing policies to address climate change. These are illustrated using findings from economic models of climate change. The main finding in these models is that the optimal mitigation-adaptation mix depends on the magnitude of climate impacts and the relative weight that society attaches to future costs and benefits relative to the present. These models also illuminate how catastrophic climate risk shapes the mitigation-adaptation balance, and shed new light on how an international agreement committing all major emitters – or equally importantly, the absence of such an agreement – affects the balance between mitigation and adaptation. In addition to these findings, this chapter briefly describes the nature of adaptation and a practical policy framework for setting adaptation priorities. Below is a summary of sections 2.2, 2.3 and 2.4. For a narrative of the main messages see section 5.

Section 2.2: The nature of adaptation

- Adaptation can be categorised using different dichotomies: (i) public vs. private; (ii) reactive vs. proactive; (iii) dedicated vs. embedded; and (iv) current- vs. capital-expenditure adaptation.

- Adaptation needs arise in a variety of areas: (i) agriculture; (ii) coastal zones; (iii) health; (iv) water resources; (v) ecosystems; and (vi) settlements and economic activity.

Section 2.3: Economic trade-offs between adaptation and mitigation

- Mitigation and adaptation to climate change are both important ingredients of climate action. They are economic substitutes, but complement one another in that greater the impact of climate change, the more of both that is required.

- The optimal adaptation-mitigation mix depends crucially on whether or not there is an international mitigation agreement. With such an agreement, the optimal policy for advanced economies comprises ambitious mitigation and moderate (mostly) anticipatory adaptation. But without an agreement, an optimal policy features relatively little mitigation, but significant adaptation.

- Even without such an agreement, aggressive mitigation can be optimal if there are catastrophic climate risks.

- Leading by example by making unilateral cuts in greenhouse-gas emissions with a view to coaxing other countries into an international climate agreement has its limits.

- Ambitious adaptation might have strategic value in international negotiations on cutting greenhouse-gas emissions.

Section 2.4: A policy framework for adaptation

- Current knowledge on future climate change, especially at regional level, is incomplete. This makes the preparation of comprehensive adaptation plans practically impossible.

- Policy should instead concentrate on (i) continuously evaluating vulnerabilities, (ii) enhancing adaptive capacity, and (iii) promoting win-win adaptation measures.

2.1 Introduction

According to the Intergovernmental Panel on Climate Change's Fourth Assessment Report (IPCC 2007a), global average temperatures would increase by about 1°C even in a scenario in which the world stopped emitting greenhouse gases in 2000. Under current policies, greenhouse-gas emissions and resulting concentrations have already exceeded their year 2000 values, and significant further increases can be expected. A higher greenhouse-gas concentration in the atmosphere will cause average global temperatures to rise further, most likely changing the world's climate far beyond what has been observed to date.

A warming climate will have a significant effect on the water cycle. Generally, precipitation will very likely increase closer to the poles, but will decrease in most subtropical land regions. These changes will increase the likelihood of droughts and floods in areas that are already at high risk of such events. For instance, by mid-century, annual river run off and water availability are expected to increase in high latitudes and decrease in dry regions in mid-latitudes. Many regions, such as the Mediterranean basin or southern Africa, will suffer a decrease in water resources.

Higher temperatures and changed rainfall patterns are likely to weaken the natural ability to absorb carbon dioxide (CO_2), thereby creating a feedback effect. In addition, thawing of permafrost releases large quantities of methane – a greenhouse gas more potent than CO_2 – that feeds back into yet higher temperatures. Such feedback effects may induce non-linear jumps in temperatures, possibly leading to runaway climate change. Feedback effects greatly contribute to higher uncertainty in the relationship between an increase in greenhouse-gas concentrations and climate change because they are difficult to model and quantify.

The expected average increase in global temperatures conceals large regional differences. Warming would be greatest over land and in areas closer to the North Pole, and least over the Southern Ocean and parts of the North Atlantic Ocean. Higher temperatures over land will increase the frequency of heat waves, likely to be worse in big cities due to the urban heat-island effect. Ecosystems in tundra and mountain regions will be more affected because of their higher sensitivity to temperature changes. Water resources in the Mediterranean, and similar regions, are likely to be greatly reduced because of less rainfall. Low-lying coastal systems will suffer disproportionately because of the higher proportion of population and infrastructure exposed to rising sea levels. Human health will be affected especially in societies with low adaptive capacity. More exposed regions are concentrated in Africa, on small islands, and in Asian and African mega deltas.

There is by now a broad consensus that mitigation and adaptation are both important – the former to limit climate change and the latter to cope with it. IPCC (2007b) states with very high confidence that:

> *"Effective climate change policy aimed at reducing the risks of climate change to natural and human systems involves a portfolio of diverse adaptation and mitigation actions".*

Mitigation actions are indispensable for addressing climate change since they could curb temperature increases. From an environmental perspective, it is enough to decide on the desired level of mitigation and then use adaptation to cope with the remaining damage from climate change. From the point of view of economic efficiency, however, this is not always the case. The reason is that adaptation and mitigation measures are often economic substitutes, and there could be policy trade-offs between the two types of measures as they compete for limited resources to achieve a similar goal – reduce climate change impacts on humans and the environment.

Economic models of climate change take into account that mitigation and adaptation are economic substitutes. These models use cost-benefit analyses that exploit the trade-offs between the two types of measures to design and analyse optimal climate policies. They integrate knowledge from climatology and other disciplines to assess the economic impact of climate change. In this sense, these models are called Integrated Assessment Models (IAM). The literature on the economic modelling of climate change is already impressive, and is growing and developing. Prominent examples are Nordhaus (2008), Stern (2007), and Bosello *et al.* (2010).

This chapter explores the economic trade-off between mitigating greenhouse-gas emissions and adapting to a changing climate. To prepare the ground, section 2.2 discusses the nature of adaptation. Section 2.3 –

which is the core of the chapter – zooms in on the trade-off between mitigation and adaptation, analysed with the help of integrated assessment models. One question to explore is how an international climate agreement – and the absence of one – affects the balance between mitigation and adaptation. Another question is how concerns about possible climate catastrophes influence the mitigation-adaptation mix. A further question is what insights these models offer for real-world climate policies. Continuing along these lines, but leaving the world of integrated assessment models, Section 2.4 briefly turns to a simple framework for the identification of EU adaptation priorities. Section 2.5 concludes.

2.2 The nature of adaptation

To examine the nature of adaptation and what sets it apart from mitigation, it is useful to start with a definition of both. The United Nations Framework Convention on Climate Change (UNFCCC) defines adaptation as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[16] An example of adaptation is the French Heat Health Watch Warning System, which is an integrated national plan for action in case of a heatwave.[17] Other examples include changing crops or the timing of the agricultural cycle of existing crops in response to long-lasting changes in the climate, and building dykes to protect against sea-level rise and more frequent extreme weather events.

Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Examples include more efficient use of fossil fuels for industrial processes or electricity generation, replacing coal- and gas-fired power plants with solar energy or wind power, and expanding forests and other 'sinks' to remove greater amounts of carbon dioxide from the atmosphere.[18]

There are measures that can be classified as both adaptation and mitigation, such as improving building insulation. There are cases, too, of adaptation that increases greenhouse-gas emissions, such as using air-conditioning systems or increasing irrigation during warmer and drier times. Nevertheless, adaptation measures are generally different from, and unrelated to mitigation measures in nature, as well as in spatial and temporal scope.

2.2.1 Types of adaptation

Adaptation can be categorised in several ways. For example, Smit *et al.* (2000) systematically specify and differentiate adaptation based on three questions: (i) adapt to what? (ii) who or what adapts? and (iii) how does adaptation occur? Stern (2007) classifies adaptation according to temporal scope – that is, short and long run – and whether or not there is a need for policy intervention. As set out in chapter 1, four dichotomies are seen as particularly useful in this publication: (i) reactive *vs.* proactive (anticipatory) adaptation, (ii) private *vs.* public adaptation; (iii) specific adaptation measures *vs*. efforts aimed at strengthening the adaptive capacity of people, firms, and society at large; and (iv) adaptation associated with capital expenditure *vs*. adaptation associated with current expenditure.

Throughout the history of mankind, adaptation has been a reaction to a changing environment. Today, because of scientific advances and ever-improving meteorological practice, people can anticipate changes in climate and extreme weather events. This allows for adaptation to start before actual changes in climate take place. In this sense, adaptation can be classified into reactive and proactive (anticipatory) adaptation. Examples of reactive adaptation are migration, changing crops or installing air-conditioners. Anticipatory adaptation may include zoning and building restrictions in areas that are expected to become flood-prone, or enhancing storm-surge barriers to cope with an expected increase in the frequency and intensity of storms.

The distinction between private and public adaptation is especially useful from a policy perspective. In essence, the distinction depends on whether the benefits arising from adaptation are fully appropriable by those who pay for them. If they are, individuals, households and businesses have the incentive to take the adaptation measures they find worthwhile. If they are not, adaptation has public-good characteristics and can be classified as public. Historically, adaptation was mostly private. People adapted to changes in climate, mostly through migration but also by changing crops or behaviour to accommodate longer periods of drought or hotter seasons. The appearance of stable and well-functioning public institutions has allowed for the provision of public adaptation, such as building floodgates or dykes.

Adaptation may be in the form of specific adaptation measures or general adaptive-capacity building. For instance, measures that improve general working or living conditions, in order to reduce medical risks can be classified as building general adaptive capacity. Higher adaptive capacity makes people and societies more resilient to changes in their environment and to climate impacts.

A final distinction is between investment (that is, the accumulation of physical assets) and current expenditures that yield instantaneous adaptation benefits. Building storm-surge barriers and other flood-protection infrastructure are typical examples of adaptation investments. Behavioural reactions to accommodate spells of extreme heat or cold weather are examples of current-expenditure adaptation.

2.2.2 Adaptation options – a sectoral perspective

Throughout this chapter adaptation is used mostly as a generic term and is referred to as a single policy tool. In practice, there are numerous adaptation options. This section discusses some of the available options. The focus is on how adaptation can address vulnerabilities to likely climate change. The discussion takes into account several studies that provide an in-depth analysis of adaptation of human and environmental systems. For instance, OECD (2008) analyses the main impacts of climate change on agriculture, coastal zones, health, water resources, ecosystems, settlements and economic activity, and extreme weather events. The authors suggest adaptation options and policy measures that might help these options to materialise.

Agriculture

Agriculture is perhaps the economic sector most vulnerable to climate change. The main impacts of climate change on this sector include the decline in global yields of crops such as rice, wheat, maize and soybean; direct and indirect impacts on farm animals; and the increased prevalence of pests, weeds and disease. In certain regions, however, agriculture may benefit from moderate climate change. Among positive impacts are increased productivity in some crops due to CO_2 fertilisation and longer growing seasons in high latitudes. The scope for adaptation to these changes is enormous. Many adverse impacts could be reduced or spread out by crop insurance, investment in new capital, and changes of crops, planting dates or farming practices. Reversing market-distorting public policies – such as heavily subsidised water supply and agriculture – and implementing policies that promote the development of heat and drought resistant crops could go a long way to facilitate adaptation in agriculture.

Coastal zones

Coastal zones are especially exposed to a changing climate. They are prone to inundation and storm damage through sea surges and backwater effects, wetland loss, erosion, saltwater intrusion in surface and ground waters, rising water tables and impeded drainage. Protection of coastal zones is mainly about providing public goods such as coastal defences, surge barriers, or saltwater intrusion barriers and therefore requires significant government intervention. Another reason for government involvement is the need for environmental management either directly by government agencies or by creating relevant markets for environmental goods and services. Land-use planning is another important policy instrument to ensure adaptation in coastal zones.

Health

People around the world are likely to suffer substantial health damages in a number of adverse climate-change scenarios. The main impacts of climate change on health include higher incidences of heat stress and heat-related mortality – counterbalanced to some extent by fewer winter deaths. Vector-borne diseases, such as malaria and dengue fever, are expected to proliferate. Many of these threats can be addressed by changing behaviour and migration patterns. Policy-relevant adaptation options include vector control programmes, disease eradication programmes, and medical and pharmaceutical research and development.

Water resources

The bulk of regional climate change impacts will mostly likely be related to water – either the lack of it or too much of it at a given place and time. More specifically, indications are that there will be a change in the volume, timing and quality of water flows, increased rainfall variability, more frequent and severe water shortages, flooding after severe water discharges, and a decline in water quality because of salination or lower/higher flows in some areas. Adapting the water sector would necessarily involve changes in water demand – loss-reduction, rational water use and rainwater collection. Water supply also needs adjusting by increasing capacity and improving water allocation. Most of the necessary adaptation will be undertaken by the private sector, including regulated water utilities. Nevertheless, there is substantial scope for policy measures such as regulatory incentives, ensuring correct price signals and facilitating financing schemes.

Ecosystems

Among the main impacts of climate change on ecosystems are changes in the extent, distribution and health of species, and species migration and behaviour, and the loss of species unable or too slow to adapt. Adaptation policy should focus on increasing ecosystem resilience, habitat protection, changes in natural resource management, environmental policy and on further developing and ensuring the proper functioning of markets for ecosystem services.

Settlements and economic activity

The main impacts of climate change in this area could be malfunctioning infrastructure, redirection of tourist flows, migration/change in population dynamics and higher energy demand from space cooling (though compensated for by a drop in winter heating demand). Adaptation options include making infrastructure climate-resilient, implementing adequate building codes, and land zoning that discourages settlements in areas especially exposed to climate risks.

To conclude, a common thread connecting the adaptation options discussed here is the necessity of functioning environmental markets, undistorted pricing, efficient insurance and smart government intervention to encourage adaptation. In real-world economies, it cannot be taken for granted that the full set of adaptation options will exist or that private and public decision makers will choose them. That said, the economic models presented in the next section return to the notion of adaptation as a generic response to a changing climate and assume that optimal adaptation decisions will be made. This allows us to focus on the key factors shaping the trade-offs between adaptation and mitigation.

2.3 Economic trade-offs between adaptation and mitigation

2.3.1 Adaptation and mitigation are inherently different

Although it is widely accepted that there is a need for both mitigation and adaptation, it is true, too, that adaptation and mitigation measures are inherently different responses to a changing climate. For one thing, adaptation aims at reducing the consequences of climate change whereas mitigation aims at limiting climate change itself. For another, mitigation of greenhouse-gas emissions is a contribution to the global public good whereas adaptation is not.

To elaborate on the second distinction, recall from chapter 1 that greenhouse-gas emissions give rise to a global negative externality – climate change. Like other negative externalities, human-induced climate change arises because emitters of greenhouse gases do not pay for the negative consequences their actions impose on others. As a result, too much greenhouse gas is released into the atmosphere. As also set out in chapter 1, human-induced climate change differs in significant ways from other negative externalities. One feature that distinguishes climate change from most other externalities is its global nature. Climate change is caused by the growing global stock of greenhouse gases, regardless of where in the world they are emitted. Equally important, cutting greenhouse-gas emissions slows down climate change, regardless of where the cuts are made. Another distinguishing feature is the timescale according to which climate change develops: those causing the negative externality and those suffering its consequences may be decades or centuries apart.

Externalities are typically addressed with taxes or subsidies, provision of public goods or regulation. These tools are all available to national or regional governments and are effective within the boundaries of their authority. On a global level, no institution exists with a mandate to coordinate contributions to a safer climate as a public good, levy taxes or enforce regulation on the scale required to address climate change. Although efforts under the UNFCCC aim at forming a common and coordinated response, the challenge of establishing cooperation is daunting as there are nearly two hundred parties (countries) with diverging and sometimes completely conflicting interests and perceptions of the costs and benefits of reducing greenhouse-gas emissions.

By and large, adaptation does not face these challenges. Unlike mitigation, it is often a private good. If a farmer changes crops in response to what he perceives to be a long-lasting change in local climate, he will most likely reap all of the increase in yields that may come with this change. Of course, adaptation can be a local or regional public good, as pointed out in section 2.2. As chapter 3 will explore, providing adaptation as a public good is not without problems, but normally there are national, regional or local governments with the authority to co-ordinate stakeholders' interests.

An important corollary of the discussion above is that decisions on adaptation and mitigation measures are taken at different levels of government – national, regional or local – and by different individuals or entities. Global mitigation measures are a function of international agreements (or the lack thereof), even if national governments formulate concrete policies, such as levying a tax on greenhouse-gas emissions or setting-up or participating in emission trading schemes. Adaptation decisions are taken by households and businesses and by local, regional or national governments. It may, therefore, be tempting to argue that there is little value in defining an adaptation-mitigation policy mix. This argument, however, would be erroneous for at least two reasons. First, economic analysis commonly posits a central, benevolent decision maker even if – in reality – decision making is dispersed. The rationale is to find out what outcome would be optimal from society's viewpoint if rational and coordinated decisions could be taken. Second, decentralised decisions may very well coincide with the optimal decisions chosen by a central, benevolent decision maker. Indeed, policies and budgets of national and regional governments ultimately depend on the preferences of households and businesses. Ultimately, voters decide on broad policies, including mitigation and adaptation, by electing parties that endorse them.[19] Representing voters, national governments take a leading role in coordinating different levels of decision-making with a view to choosing a mix of mitigation and adaptation that is best from society's viewpoint.

Finally, an important difference is that mitigation and adaptation work on very different timescales. It takes mitigation several decades before it has some impact on the stock of greenhouse gases in the atmosphere because of the substantial inertia of the carbon cycle. Adaptation, by contrast, becomes effective immediately or with time lags typical for standard investment projects – ranging from a few months to a few years.

2.3.2 Mitigation and adaptation: complements or substitutes?

While there is broad agreement that the climate is changing, there is substantial uncertainty about the pace and scale of climate change. According to current knowledge, it could be relatively slow and manageable, but it could also be dramatic, abrupt and irreversible with catastrophic effects. Given this uncertainty, formulating effective policies to limit global warming and reduce the impacts from expected climate change is a challenge. It seems clear, however, that adaptation and the acceptance of residual damage from climate-change impacts are part of the policy toolbox, in addition to mitigation measures. All in all, there seem to be trade-offs between mitigating and adapting to enduring climate change.

Trade-offs are inherently unpleasant, and when confronted with them people are inclined to hope that they can have it all – both mitigation and enough adaptation to avoid residual damage from climate change. Arguments that adaptation and mitigation are complements permeate the climate-change debate. For example, in the IPCC's chapter on adaptation (see IPCC, 2007b), the arguments that adaptation and mitigation complement one another outnumber those suggesting that they are substitutes. Economic reasoning does not reject these arguments. In fact, depending on the perspective, adaptation and mitigation can be both complements and substitutes.

To see why the perspective matters, note that one can tell economic substitutes and complements apart when their relative prices change. Suppose mitigation costs fall relative to adaptation costs. If it is possible to mitigate more without having to adapt more at the same time, then mitigation and adaptation are economic substitutes. This seems to be the case. For example, it is always possible to have more wind farms (*i.e.,* mitigation) without the need for better flood protection (*i.e.,* adaptation). By contrast, if extra mitigation were to require extra adaptation, mitigation and adaptation would be economic complements. With mitigation and adaptation being economic substitutes, a decline in the relative cost of mitigation makes it worthwhile for society to substitute mitigation for adaptation – that is, mitigate more and adapt less – while still achieving the same benefit from the new combination of mitigation and adaptation as from the previous combination. By extension, an increase in the relative cost of mitigation argues in favour of mitigating less and adapting more, provided that the new mitigation-adaptation mix gives society the same comfort as the old one. Clearly, this cannot be taken for granted as – to return to the example above – additional flood protection cannot indefinitely substitute for fewer wind farms.

To change perspective – and to explain why mitigation and adaptation are often considered to complement one another – assume again a decline in mitigation cost but assume now that society wants to use the resources saved as a result of the cost reduction for stepping up its level of comfort in the face of a changing climate. Alternatively, simply assume that society wants to allocate more resources to the climate challenge – regardless of any change in the relative costs of mitigation and adaptation. Under both scenarios, society is likely to allocate some of the additional resources to mitigation and some to adaptation. Thus, adaptation and mitigation will increase in tandem, and in that sense they are often seen as complementing one another. Even in these circumstances there are trade-offs, however, as society needs to decide how to split additional resources between adaptation and mitigation. Mitigation and adaptation also appear as complements if society learns that, unless climate efforts are stepped up, the impact of climate change will be worse than previously anticipated. Most likely, society will then step-up both its adaptation and mitigation efforts. Conversely, if society were to find out there is less to worry about manmade climate change, it will most probably save on both mitigation and adaptation expenditure.

In summary, depending on the frame of reference, mitigation and adaptation might be seen as substitutes or complements. From a strict economic perspective, they are substitutes and there is, alas, the inevitable need to choose between spending on either mitigation or adaptation. It is this notion that runs through the remainder of this section.

2.3.3 Economic models of climate change

Building on the economics of climate change introduced in chapter 1, this section broadens the perspective by explicitly accounting for adaptation as an element of a balanced climate policy mix. More specifically, this section starts by elaborating on the trade-off between mitigation and adaptation and the opportunity cost of both. It then sketches the implications for the mitigation-adaptation mix of discounting and uncertainty. This is followed by a few remarks on how scientific progress, learning and irreversibility affect the mix. Finally, the section ends with a consideration of the importance of an international climate change agreement for the proper balance between mitigation and adaptation. These themes can be seen as a prelude to the mitigation-adaptation model presented in section 2.3.4.

Economic trade-offs

From an economic point of view, good management of the climate system requires the incremental benefits from increasing greenhouse-gas emissions, say by one tonne, to be balanced against the additional cost that this tonne is expected to impose by exacerbating climate change.[20] To put it differently, there should be a balance between the costs of reducing emissions marginally today and the benefits of less climate change in the future. In addition, good economic management requires a comparison of the costs incurred today to reduce future climate change with the cost of adapting to or enduring this climate change. If it costs less for society to adapt, then adaptation should be increased at the expense of mitigation.[21]

Thus, reducing greenhouse-gas emissions today can simply be viewed as an investment in climate. When deciding on it, one should compare the expected return to the return on other investments (*e.g.*, in education, productive capital and research and development) and the benefits from consumption. Investing a lot in mitigation may prevent climate change from happening, but it might also have a negative effect on welfare (see chapter 4). Conversely, investing little in mitigation today may lead to a substantial climate-change related cost that may outweigh the benefits of other investments.

Basic economic principles mandate that this competition for resources between climate investment and other uses will yield the greatest benefit if the rates of return of all uses equalise at the margin, *i.e.,* the last euro spent on each use of resources should bring the same additional benefit. The application of this principle yields clear policy recommendations: reduce emissions until (i) the costs of cutting them equal the social benefits of reduced emissions and (ii) the return on climate investment equals the rate of return on other investments; and invest in adaptation until the last euro spent on it brings the same benefit as the last euro spent on mitigation.

Models based on these principles often produce an optimal policy that starts with modest cuts in greenhouse-gas emissions, which do not differ substantially from business-as-usual, at least in the next twenty years or so. The related social cost of carbon is estimated to be rather low today and to rise gradually in the future. Initial adaptation effort is accordingly low. This result runs against the perception that mankind faces substantial damage from climate change unless emissions are cut aggressively and resolutely, starting today. A number of reasons explain this apparent controversy, including perhaps too radical simplifications built into many economic models, and controversial ethical judgements about intergenerational discounting.

Social discount rates and uncertainty

Chapter 1 discusses in some detail the incorporation of uncertainty into economic models of climate change and the controversies surrounding the social discount rate used in these models. As argued there, optimal greenhouse-gas mitigation varies substantially depending on how uncertainty and discounting is modelled.

Adaptation may also be sensitive to discounting, though the size of the effects depends on whether adaptation is reactive or proactive. Reactive adaptation is less directly affected by the choice of discount rates because, unlike mitigation, adaptation spending is assumed to take place simultaneously with the damage. Thus, discounted to the present, adaptation spending may be low, but in absolute terms it may still be significant, depending on the intensity of future climate impacts. Proactive adaptation investment and adaptation capacity building are more sensitive to the choice of discount rate.

In common with discounting, uncertainty affects adaptation less than mitigation and the effects on the mix of adaptation measures are more pronounced. Reactive adaptation is not very sensitive to uncertainty assumptions and therefore varies little. Proactive adaptation is more sensitive, and tends to rise the more realistic the treatment of uncertainty.

Scientific progress, learning, and irreversibility

Among the most important missing ingredients in many current models are non-linearities (implying a possibly abrupt climate change) and fat tails (implying non-negligible catastrophic risk). These are related to the substantial lack of knowledge about the link between global warming and climate change. For instance, the increase in the global average temperature may reach a threshold beyond which climate change accelerates with each additional degree of temperature increase. There may be sizeable feedback effects that cause similar non-linear outcomes. The probability of a catastrophe may also rise non-linearly with an increase in temperature. Introducing non-linearities, fat tails and feedbacks in economic models greatly complicates them and is still work in progress, but has the potential to make these models even more relevant for policy analysis. Such effects might dramatically change the motivation to mitigate, even in the absence of an international climate-change agreement.

Although proper treatment of uncertainty and non-linear changes in climate are still not mainstreamed in integrated assessment models, it is already known that, all else being equal, mitigation should be more aggressive, thereby reducing the scope of adaptation. This is because people would take into account that climate-change risks are skewed towards large negative outcomes and, therefore, would take precautions by cutting emissions more vigorously.

Ingham *et al.* (2007) explicitly consider two other factors possibly shaping the climate policy response: the irreversibility of the greenhouse-gas concentration in the atmosphere and the possibility that climate uncertainty resolves as climate science advances. Irreversibility simply reflects the fact that even with no emissions, it is very difficult to reduce the greenhouse-gas concentration in any given period beyond natural decay.[22] This constraint is relevant for policymaking since it requires bigger emission reductions in earlier periods (more aggressive mitigation) than would be required without such a constraint. The intuition is straightforward: if one expects that in some future period emissions should be reduced below what will be feasible in that period, then reductions should start already today in order to avoid the binding constraint in the future.

Ingham *et al.* (2007) combine the possibility that climate uncertainties will be resolved – at least partially – as science progresses with irreversibility, and examine what this combination implies for mitigation. They find that adaptation weakens the relationship between mitigation and the irreversibility of emissions described in the preceding paragraph. The idea is that future knowledge about climate change will be better and, consequently, costly mitigation decisions will be better informed. Against this background, it makes sense to mitigate less and put more emphasis on adaptation to buy the time necessary for science to advance.

Scope for international cooperation on climate-change mitigation

International cooperation or lack thereof is a key determinant of the optimal policy mix. Rather unrealistically, most integrated assessment models assume international cooperation.[23] Lack of cooperation, however, may change the optimal policy mix dramatically. The reason is that without cooperation, there are few incentives to mitigate. To see why, consider a country – or a bloc like the EU – that plans to cut its greenhouse-gas emissions. When acting alone, the country carries the entire cost of its action, but shares the benefit of slower climate change with other countries, because they cannot be excluded from these benefits. In these circumstances, the country acts only up to the point where the marginal benefit accruing to it equals the marginal cost of its own action. It is rational for all other countries to behave in a similar manner, but even if they did, the aggregate cut in emissions would fall short of what is optimal for the world community. This is because from a global perspective, emission cuts should be taken up to the point where the global marginal benefit equals the marginal cost of cutting emissions, and this condition typically implies greater cuts than the sum of cuts resulting when each country acts on its own without cooperating with others. In sum, unless countries cooperate, mitigation falls short of its global social optimum. This holds even if countries individually internalise the climate-change externality as they perceive it.

Too little mitigation in the non-cooperative case brings about more climate change and associated damages. Consequently, adaptation remains the only effective instrument to reduce the impact. This is because adaptation does not have the characteristics of a global public good. A dyke protects only a small area and it therefore suffices to coordinate its financing only within that area. Making a house or a public building more resilient to climate impacts benefits only the owners and they thus have the incentives to adapt.

Credibly increasing adaptation at the expense of mitigation may have feedback effects on the non-cooperative outcome described above. Some researchers, for instance Auerswald *et al.* (2011), argue that adaptation policy has a vital role in international climate negotiations. Adaptation reduces the impacts of climate change on countries and creates an advantage that can be used to coax other countries or regions to cooperate. This is possible due to the public-good nature of mitigation. A country's mitigation efforts are positively related to its income and the benefits from reducing climate change. These benefits are less the less the vulnerability of a given country to climate-change, and this vulnerability can be reduced through adaptation measures. Thus, countries that invest in adaptation reduce their incentives to mitigate and this forces other countries to increase their mitigation efforts. Box 1 outlines alternative ways to establish international cooperation on climate action.

Box 1: Architectures for an international agreement on climate-change policies

The Kyoto Protocol is the most significant and encompassing international agreement on climate change to date. It established commitments on the part of industrialised countries to reduce their greenhouse-gas emissions by the period 2008-2012 relative, in most cases, to 1990, and was intended as a first step towards long-term international cooperation. The Protocol established a number of market-based mechanisms, which aim at cutting emissions in the most cost-effective manner.

The Protocol is praised by many for being the first and, for now, the only international agreement to reduce emissions. Its market-based provisions ensure the cost-effectiveness of emission reductions and the exemption of developing countries is praised for ensuring distributional equity. The Protocol is not without weaknesses, of course, the biggest being that three of the five most important countries – China, India, and Russia – did not have to commit to emission reductions, and the then-largest emitter, the United States, did not ratify the agreement. The Protocol did not provide good incentives for all countries to participate, and the incentives to comply are deemed inadequate. The lack of long-term targets and commitments is highlighted as another major deficiency.

The Kyoto Protocol first commitment period ends in 2012 and a successor is still in the making. This successor should ideally build on the strengths and weaknesses of the Protocol, whether or not it assumes a form that is similar to the Protocol. According to Aldy and Stavins (2007), possible agreements can be grouped into three broad categories. The most familiar is typically labelled 'targets and timetables' – the Kyoto Protocol is of this nature – which sets country-specific emission targets to be achieved over a specified period of time. Bosetti and Frankel (2012) propose a framework along the lines of the Kyoto Protocol while avoiding its major shortcomings. This proposal envisages that countries reduce emissions according to decade-by-decade formulas that take into account past emissions, income and other country-specific variables. International emissions trading should provide efficiency and allow developing countries to gain from trading their relatively more generous allocations.

The second approach rests on 'harmonised domestic policies' such as an agreement on harmonised domestic carbon taxes. This approach puts at the centre of the discussion the political economy of the international process and the incentives of the different parties to join an agreement. Proposals in this category acknowledge the absence of international institutions strong enough to enforce quantitative emission targets. Therefore, they build on the strength of existing national or regional institutions. One example of this approach is Stoft (2008), whose proposal includes a mechanism that provides an incentive for countries – rich and poor – to participate and to set carbon taxes at the same level. McKibbin and Wilcoxen (2007) propose an architecture based on national emission trading schemes, and governments that coordinate and harmonise allocations at the international level.

The final category includes agreements on 'coordinated but unilateral national policies'. Architectures in this group rely on a 'bottom-up' approach, contrary to architectures in the previous two groups. The idea is that countries and regions should experiment with different unilateral approaches that would evolve and eventually morph into a unified global approach. Victor (2011) is one proponent of this method, arguing that it is the most realistic and, thus, promising strategy for addressing the global public-good market failure.

Unsurprisingly, the 2011 climate summit in Durban stayed on the targets-and-timetables track for finding a post-Kyoto agreement. The main outcome of the summit was the Durban Platform for Enhanced Action. It commits all countries to negotiate a new treaty by 2015 and put it into force by 2020. The envisaged treaty from the Durban Platform foresees emissions reduction targets for all countries. This is a marked departure from the Kyoto Protocol, which sets emission reduction targets only for developed countries.

2.3.4 International climate-change cooperation, catastrophic climate risk, and the mitigation-adaptation mix

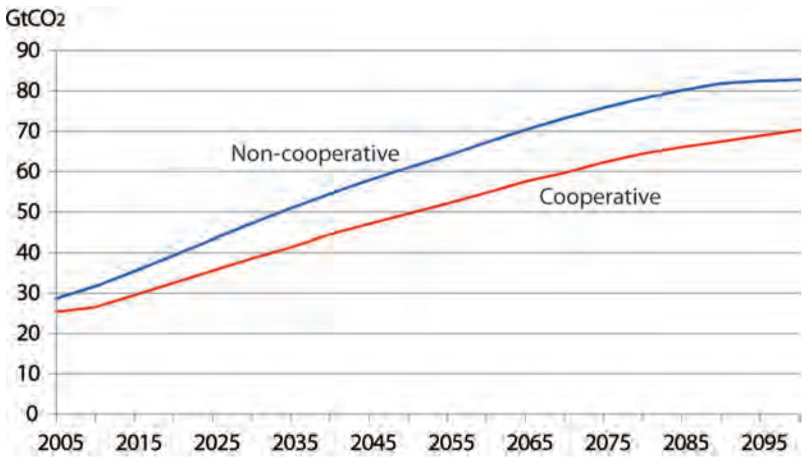
So far we have qualitatively analysed the various factors that determine the optimal mitigation-adaptation mix. As these factors affect mitigation and adaptation in different, possibly opposing ways, it is nearly impossible to say what the net outcome will be. Quantitative analysis approaches this problem by calibrating models to resemble as closely as possible real-world economies using a number of metrics. These models are solved so that optimal policies, the right balance between mitigation and adaptation, and prices can be determined and their development over time can be simulated. Two such models will be presented here – both are based on the so-called AD-WITCH model.[24] Both models incorporate many of the important determinants of climate-change policy discussed above, but which are often omitted from other integrated assessment models. The first model (section 2.3.4.1) illustrates the role of international climate cooperation for the optimal mitigation-adaptation balance. The second model (section 2.3.4.2) illustrates the role of possible climate catastrophes for the optimal mitigation-adaptation balance.

2.3.4.1 The effect of international climate-change cooperation on the mitigation-adaptation mix

This section draws on the results of Bosello *et al.* (2010). In a non-cooperative scenario in which there is no international climate agreement, countries have virtually no incentive to cut emissions. The upper line in Figure 1 shows global greenhouse-gas emissions for this scenario. By contrast, in a cooperative scenario in which there is an international climate agreement, the climate-change externality of greenhouse-gas emissions is internalised and there are no incentives to free-ride on the mitigation efforts of the others. The lower line in Figure 1 shows the emission path for this scenario. The difference between the two lines captures greenhouse-gas mitigation resulting from international cooperation. In this model, an international climate agreement reduces cumulative global emissions by about 18 percent.

Figure 2 shows the optimal adaptation expenditure for each scenario. As expected, without cooperating on emission cuts, there is a greater need for

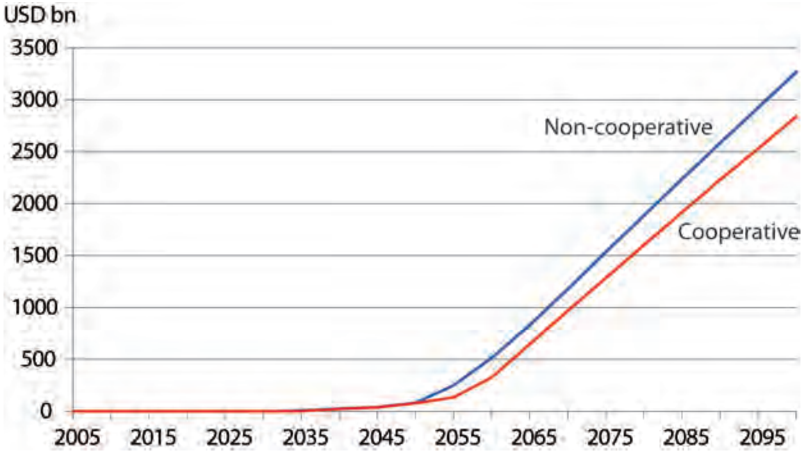
Figure 1. Global CO_2 emissions (in gigatonnes) with and without international cooperation



Source: Bosello *et al.* (2010)
Notes: Normal climate damages are accounted for, but not the risk of catastrophe.

adaptation than with cooperation. That is, the additional adaptation substitutes for the lack of mitigation. That said, adaptation is negligible for the first half of the century, but becomes a significant part of the policy mix in the second half. Comparing the time profile of mitigation (*i.e.*, the difference between the two lines in Figure 1) with the time profile of adaptation (Figure 2) reveals a significant difference in the timing of the two types of measures. Mitigation starts early because it takes a long time to work through the inert carbon cycle. Accordingly, in order to reap some benefits by the mid-twenty first century, mitigation has to start two to three decades earlier. Adaptation, by contrast, works through the much shorter economic inertia and therefore is implemented much later.

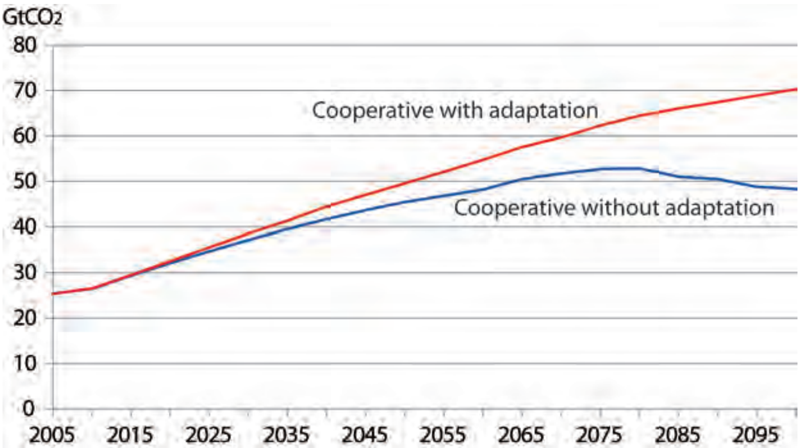
Figure 2: Global adaptation expenditure (in billion USD) with and without international cooperation



Source: Bosello *et al.* (2010)
Notes: Normal climate damages are accounted for, but not the risk of catastrophe.

Figures 1 and 2 give a flavour of the trade-off between mitigation and adaptation: a greater effort to cut emissions (that is, when there is climate cooperation) means less need to spend on adaptation. However, the trade-off can be shown more clearly by comparing optimal emissions with and without adaptation. The comparison is between optimal emissions in a world in which optimal adaptation is feasible, and optimal emissions in a world in which adaptation is so costly that it is not undertaken at all. For the cooperative scenario, Figure 3 plots emissions under the optimal policy mix, and for a scenario in which adaptation is not possible. The difference between the upper and the lower lines indicates the required cuts in greenhouse-gas emissions if adaptation is forced out of the optimal policy mix. To put it differently: adaptation reduces the need to mitigate because emissions in the presence of adaptation are higher by some 45 percent by the end of the century. That said, as the difference between the upper and lower lines in Figure 1 shows, mitigation nonetheless remains an important and far from negligible component of the optimal cooperative response to climate change.

Figure 3: Global CO_2 emissions (in gigatonnes) with and without adaptation



Source: Bosello *et al.* (2010).
Notes: Damages from gradual and smooth climate change are accounted for, but not the risk of catastrophe. With cooperation on cutting greenhouse-gas emissions.

2.3.4.2 The effect of catastrophic climate risk on the mitigation-adaptation mix

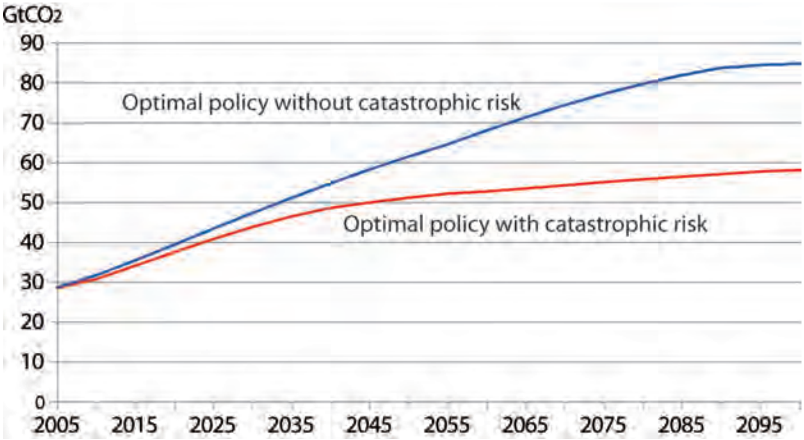
Bosello *et al.* (2012) assume no cooperation on climate action between countries/regions and compare two different climate change scenarios – with and without risk of climate catastrophe.

Without catastrophic climate risk, climate change occurs gradually and smoothly. This may seem unrealistic given that climate scientists do not exclude major changes in climate that may trigger catastrophic outcomes, such as sudden disruption of the Gulf Stream or the collapse of the West Antarctic ice sheets. It is nevertheless a useful benchmark as it can be viewed as a scenario in which society believes that there will be no major catastrophe. In the absence of international cooperation on mitigation, policies at the country/regional level are chosen to equalise marginal benefits and marginal costs, without taking into account the externalities imposed globally. Because of the free-riding incentive, little mitigation effort is thus undertaken. The upper line in Figure 4 shows emissions under this scenario. Not surprisingly, this trajectory is very similar to that shown by the upper line in Figure 1.

With catastrophic climate risk, things change considerably. Note first that Bosello *et al.* (2012) introduce a non-trivial risk that a climate catastrophe inflicts damage equal to a quarter of world output. More importantly, this risk is endogenous, that is, more mitigation reduces it. By contrast, adaptation has no effect on it. The key point, then, is that by varying mitigation, policies can influence the likelihood of a catastrophe. This assumption changes substantially the optimal policy relative to the scenario without catastrophic risk. In fact, emissions are cut considerably – as the lower line in Figure 4 indicates – even though all countries/regions continue to act only in their own interests given the assumption that they do not cooperate on climate action. But given the risk of catastrophe, the benefit of climate action to each country/region has increased to an extent that it makes emission cuts worthwhile despite the fact that each country/region continues to ignore the externality it imposes on others.

More mitigation in the catastrophic-risk case comes at the expense of adaptation, as shown by Figure 5, which plots global adaptation expenditure

Figure 4: Global CO_2 emissions (in gigatonnes) with and without catastrophic climate risk

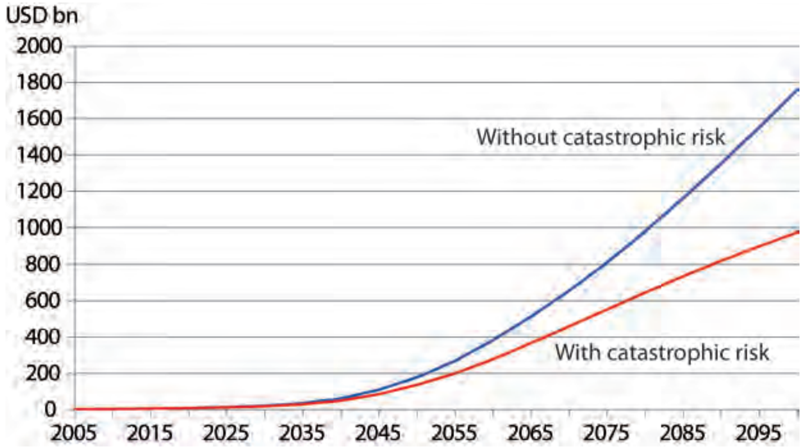


Source: Bosello *et al.* (2012)
Notes: Both paths assume absence of international cooperation on climate action.

with (lower line) and without (upper line) catastrophic risk. In the presence of catastrophic risk, aggressive mitigation efforts halve adaptation expenditures relative to the without-risk scenario. This should be expected since more aggressive mitigation reduces climate change and therefore the need to adapt to it.

It is instructive to look more closely at the trade-off between mitigation and adaptation in the presence of catastrophic risk. This can be done most clearly by eliminating adaptation from the mitigation-adaptation mix (*e.g.*, assuming that it is far too costly) and, then comparing the resulting level of greenhouse-gas emissions with the level of emissions under the optimal mitigation-adaptation mix (lower line in Figure 4). Figure 6 plots the difference in emissions resulting from an optimal mix of adaptation and mitigation and a mitigation-only policy. The difference is very small, suggesting that the ability to use adaptation has little practical effect on mitigation when catastrophic risk is present. The reason is that mitigation is motivated by the endogenous link between emissions and the risk of a catastrophe. Since adaptation does not influence this risk, the optimal

Figure 5: Global adaptation expenditure (in billion USD) with and without catastrophic climate risk

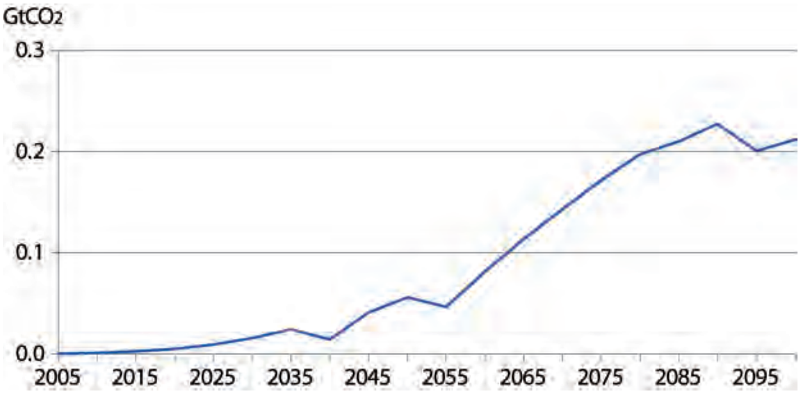


Source: Bosello *et al.* (2012).
Notes: Both paths assume absence of international cooperation on climate action.

mitigation policy is very weakly linked to adaptation measures. In sum, assuming catastrophic risk drastically reduces the ability of adaptation to substitute for mitigation.[25]

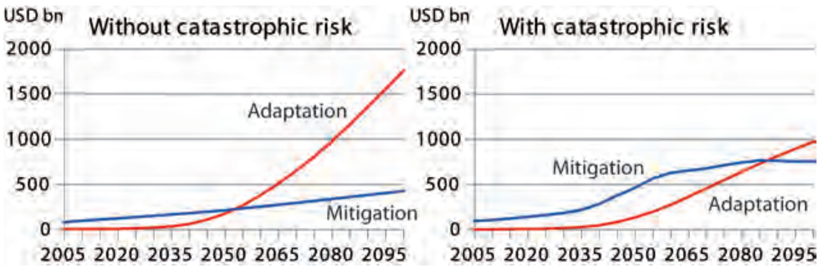
The work of Bosello *et al.* (2012) also illustrates the impact of catastrophic climate risk on global mitigation and adaptation expenditures. Mitigation is the (indirect) result of investment in different energy technologies and research and development. Higher mitigation therefore requires more resources. The left-hand panel of Figure 7 plots expenditures on mitigation and adaptation for the cases without catastrophic risk; the right-hand panel of Figure 7 shows the same expenditures with catastrophic risk. Adaptation expenditures in the presence of catastrophic risk are considerably lower than adaptation expenditures in the no-risk case in each period. Furthermore, in contrast to the no-risk case, adaptation expenditures in the presence of catastrophic risk are, in most periods, lower than mitigation expenditures. This is not only because more mitigation reduces the need for adaptation, but also because adaptation competes with mitigation for limited resources.

Figure 6: Difference in CO_2 emissions (in gigatonnes) between optimal mitigation–adaptation mix and mitigation only in the presence of catastrophic risk



Source: Bosello *et al.* (2012).
Notes: It is assumed that there is no international cooperation on climate action.

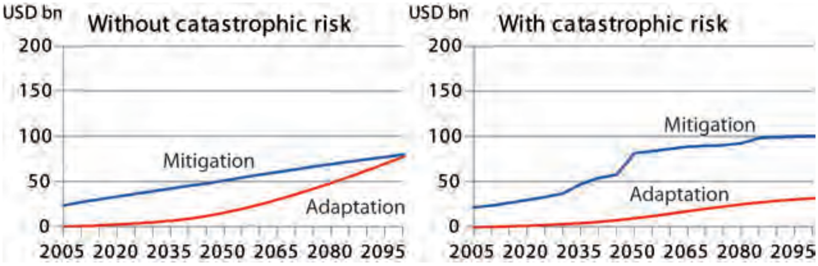
Figure 7: Global mitigation and adaptation expenditures (2005 Billion USD) without (left panel) and with (right panel) catastrophic risk



Source: Bosello *et al.* (2012).
Notes: It is assumed that there is no international cooperation on climate action.

The crowding-out of adaptation by mitigation is even stronger for the EU. Figure 8 plots the same variables as Figure 7 but for the EU: expenditures on mitigation and adaptation for the cases without catastrophic risk (left-hand panel), and with it (right-hand panel). Relative to the no-risk case, EU adaptation expenditures in the presence of catastrophic risk are cut in half by the end of the century, while mitigation is increased by about 50 percent.

Figure 8: EU mitigation and adaptation expenditures (2005 Billion USD) without (left panel) and with (right panel) catastrophic risk

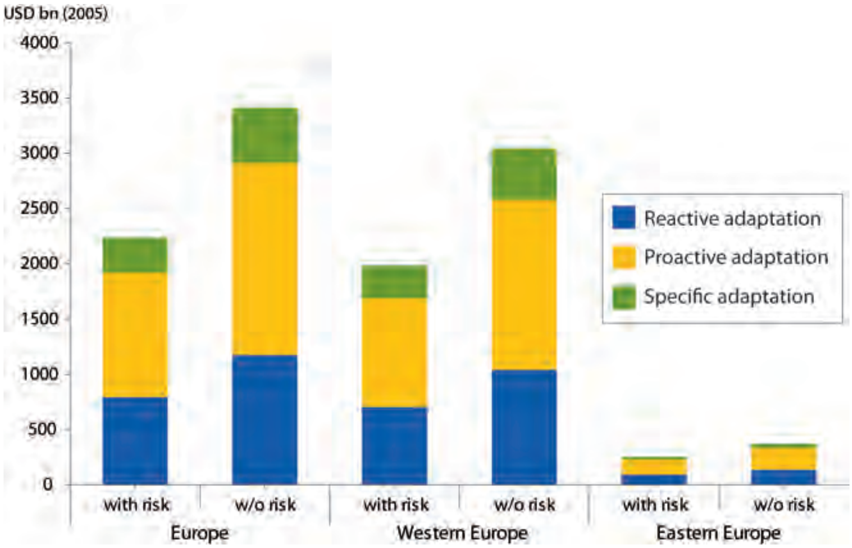


Source: Bosello *et al.* (2012).
Notes: It is assumed that there is no international cooperation on climate action.

The analysis also allows adaptation expenditures to be broken down according to different categories of adaptation for different regions. Figure 9 plots cumulative adaptation expenditures for the twenty-first century with and without the presence of catastrophic risk; expenditures are shown for Europe and separately for western and eastern Europe. It shows that the presence of catastrophic risk does not alter substantively the structure of adaptation expenditures – neither in Europe as a whole nor in its two parts. Throughout the century, in Europe, the most important adaptation category is proactive adaptation, followed by reactive expenditure and investment in adaptive capacity building. The situation is similar in western and eastern Europe, although the difference between proactive and reactive adaptation is much less for eastern Europe.[26]

The simulation of Bosello *et al.* (2012) also offers a fresh view on the role of discounting for mitigation and adaptation. To start with mitigation, without catastrophic risk, and keeping in mind that this is the non-cooperative case, the level of the social discount rate matters very little for the greenhouse-gas emissions path (see the top two lines in Figure 10). This is because without climate cooperation, each country, or region, does not account for the external damage it imposes on others. Thus, even though a lower

Figure 9: Cumulative EU adaptation expenditures (in billion USD) by category with and without catastrophic risk

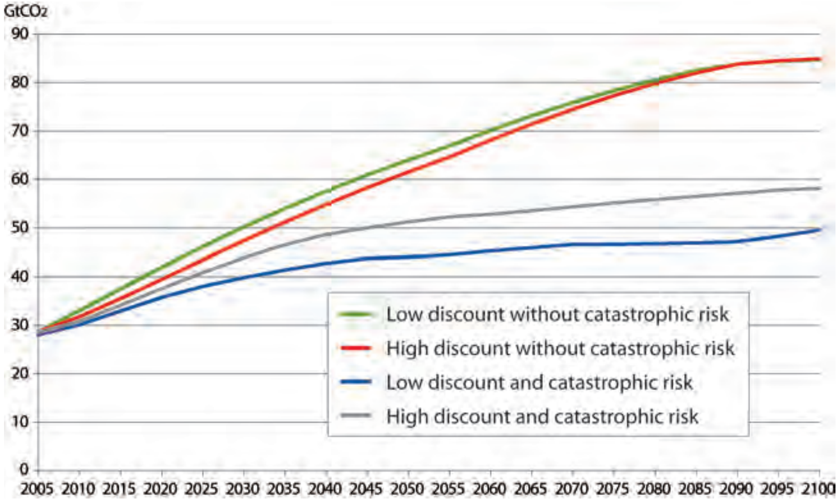


Source: Bosello *et al.* (2012).
Notes: It is assumed that there is no international cooperation on climate action.

discount rate favours increased mitigation, it also favours higher future consumption and emissions. Both effects broadly cancel each other out. The outcome changes in the presence of catastrophic risk (the bottom two lines in Figure 10), in which case the first effect clearly outweighs the second.

It is intriguing to see that lowering the discount rate has opposite effects on adaptation expenditures with and without catastrophic risk – as shown by Figure 11. While lower discounting reduces adaptation expenditures without catastrophic risk, it encourages higher adaptation expenditures with catastrophic risk. Thus, in the presence of catastrophic risk, lower social discount rates imply both more mitigation and adaptation than higher social discount rates. The key insight here is that introducing catastrophic risk moves non-cooperative policies closer to the cooperative optimal policy mix.

Figure 10: Global CO_2 emissions (in gigatonnes) with and without catastrophic risk for low and high social discount rates



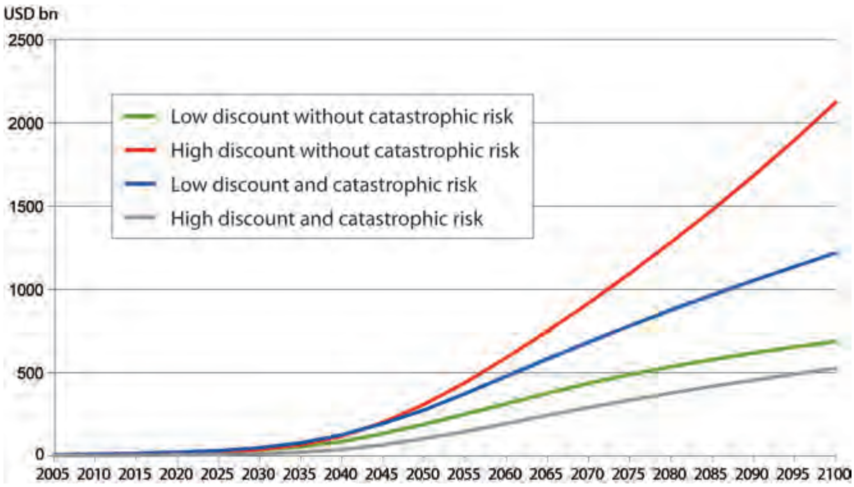
Source: Bosello *et al.* (2012)
Notes: It is assumed that there is no international cooperation on climate action.

2.3.5 Economic models and policy recommendations

Economic models of climate change are just that – models: abstractions and simplifications of the real world. Therefore, the insights they offer should not be taken literally as policy prescriptions. Nevertheless, due to their internal consistency and discipline, economic models are indispensable tools for analysing policy challenges, and they set benchmarks for assessing and understanding real-world policies. Bearing this in mind, the remainder of this section briefly considers three issues: first, divergence between real-word and optimal policies, second the notion of 'leading by example' in the fight against climate change and, third, fear of climate catastrophe.

In general, economic models stress the concept of optimality, but it is not clear how one can translate this into the real world. Lack of cooperation on climate change should lead, according to economic models, to negligible mitigation efforts. Yet, national climate policies differ substantially even in

Figure 11: Global adaptation expenditure (in billion USD) with and without catastrophic risk for low and high social discount rates



Source: Bosello *et al.* (2012).
Notes: It is assumed that there is no international cooperation on climate action

relatively homogeneous groups of countries, such as OECD members. EU countries have collectively committed to quantitative targets and timetables for reducing greenhouse-gas emissions and they have established a pan-European emissions trading scheme (EU ETS). They have also committed to further cuts if a satisfactory international climate agreement is reached. At the same time, other OECD countries have not made such commitments. The United States declined to ratify the Kyoto Protocol and Canada has withdrawn from it. Such divergence raises the question of whether existing national mitigation strategies could all be optimal at the same time.

The analysis in the preceding sections makes clear that due to the global character of the climate-change externality, national and global optima do not coincide without international cooperation. Thus, in the absence of such cooperation, national policies are driven by what is optimal from a national rather than a global perspective. Countries are very different, even within the OECD, because their social preferences, geographies and exposures to climate change vary substantially. The implication is that their policies could indeed be optimal from their perspective.

This leads to the issue of leading by example given that EU countries pursue mitigation policies that, from economic models and in the absence of an international climate agreement, are clearly more ambitious than those following. One motivation certainly is to convince other countries to follow. However, Geden (2010) argues that due to intrinsic country differences, it is very unlikely that leading by example will persuade followers to join a global agreement on stopping climate change. He notes that such a policy will only be successful if it demonstrates that decarbonisation actually works. Hence, if Europe is able to demonstrate that a low-carbon economy is feasible and profitable, all other countries will follow driven solely by self-interest. If leading by example turns out to be unsuccessful, however, there is a case for re-orienting climate action from mitigation towards adaptation.[27] The German Council of Economic Advisers argues, in a similar vein, that a policy of leading by example cannot be sustained indefinitely if the rest of the world does not follow. The alternative should be stepping up adaptation, which could be used as a strategic tool to coerce others to cooperate on climate-change policy (*Sachverständigenrat*, 2011). More generally, cognizant of the trade-offs between adaptation and mitigation, climate-change policies could be enriched by making contingency plans that include both mitigation targets and adaptation measures depending on the level of international cooperation.

The analysis in section 2.3.4 also suggests another justification for divergence of national policies – catastrophic risk. In a world in which climate change is smooth and reversible and there is no international climate cooperation, mitigation is just a marginal option. It is necessary and welfare-improving, but much less important than adaptation. When catastrophic risk is perceived as real, however, mitigation becomes a key policy variable, regardless of its ability to reduce non-catastrophic damages. The reason is that only mitigation can reduce the likelihood of a climate catastrophe. In these circumstances, mitigation is motivated mostly by precaution and is relatively independent from adaptation. Adaptation is mostly needed to tackle the residual damage that was not addressed by mitigation.

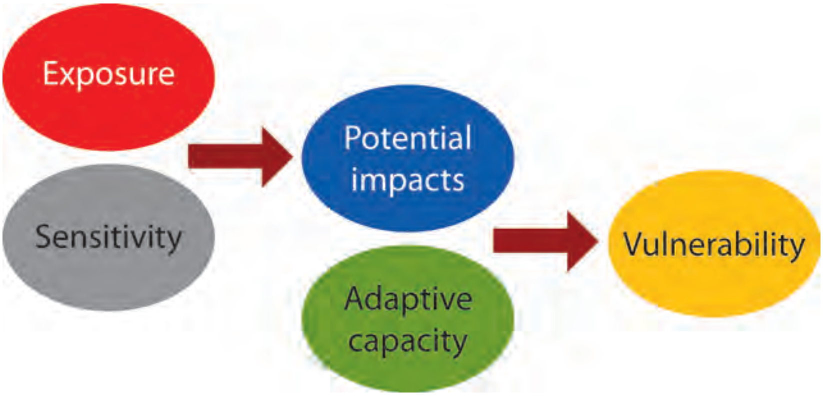
2.4 A policy framework for adaptation

According to the model in section 2.3, most EU adaptation expenditures will not be needed before 2030 (see Figure 8). Nevertheless, there are reasons why adaptation to climate change should not be overlooked today. The aim of this section is to discuss the priorities and issues of current adaptation policy. In doing so, it draws mostly on Fankhauser and Soare (2012).

Reactive adaptation to ongoing changes in climate is relatively straightforward to design and implement. This is not the case for anticipatory adaptation to future climate change. This kind of adaptation will very likely dominate the EU adaptation response (see Figure 9). The further into the future these changes are, the more difficult or practically impossible it becomes to tackle adaptation using a so-called 'science-first' approach. This approach rests on devising regional plans to adapt to a broad contingency of climate-change events, the impacts of which need to be carefully quantified by impact assessments. This, however, is practically infeasible since knowledge of future climate change in a given region is very limited. Against this background, Fankhauser and Soare (2012) favour a so-called 'policy-first' approach, whereby policymaking starts with an assessment of the current situation by reviewing existing procedures to deal with climate events, and inquire how procedures might have to change in response to a changing climate. The goal is to devise measures that are sensible and robust given society's limited knowledge of what the exact future climate will be.

The key pillar of this approach is an assessment of vulnerabilities to climate change. As Figure 12 illustrates, vulnerability depends on a combination of factors. More specifically, exposure to climate change and sensitivity to this exposure jointly determine climate change impacts, and impacts together with the adaptive capacity of a system determine climate change vulnerability. To elaborate, exposure refers to the climate stimuli impacting on a system, for example, the extent of warming observed. Sensitivity captures the degree to which the system is affected by changes in climate parameters, for example, the share of GDP of climate-sensitive sectors such as agriculture. Adaptive capacity refers to the ability of a system to deal with the potential impacts, for example, the quality of emergency services in a country.

Figure 12: Vulnerability is a function of exposure, sensitivity, and adaptive capacity.



Source: Barr *et al.* (2010) and Fankhauser and Soare (2012).

To consider each of these determinants individually, note first that information on exposure to climate change is provided by scientific studies detailing scenarios that set out the possible evolution of temperatures. Given the temperature increase, scientists predict likely changes in precipitation, sea-level rise and extreme weather events. Second, to assess the impacts of climate change on a society, one needs to evaluate the society's sensitivity to change. This depends on a number of underlying characteristics. The degree of sensitivity of the economy is key. To illustrate, economies with a high share of agriculture or tourism are more sensitive to climate-change exposure than others. The sensitivity of the natural environment and its management is another relevant characteristic. Factors such as water availability and use, and the number of people and structures in coastal zones are important here. The sensitivity of the structure and organisation of society itself is also an important factor in determining the overall sensitivity to climate-change exposure. For instance, a high share of elderly people increases society's sensitivity to extreme weather events, such as heatwaves.

Societies with similar exposure and sensitivity may still be vulnerable to a different degree due to differences in adaptive capacity. The adaptive capacity of a society varies according to factors such as income per capita, income inequality, education, access to insurance and finance, and the quality of institutions. The relationship between these factors and a society's capacity to adapt is not perfect and far from uniform. For instance, EU members score similarly on most of these counts but differences in adaptive capacity nevertheless exist.

The response in France in the wake of the 2003 heatwave and the response of Greece to the 2007 wildfires, widely discussed in the literature on adaptation and adaptive capacity (see Pascal *et al.,* 2006; INSERM, 2006; Tsaliki, 2010; and Xanthopoulos, 2011), illustrate the contrasting adaptive capacities within the EU. Fankhauser and Soare (2012) review and compare both responses. August 2003 was the warmest month ever recorded in the northern hemisphere. It resulted in a death toll of over 14,800 people in France, out of 35,000 in Europe as a whole. In response, France developed the Heat Health Watch Warning System (HHWWS) on the basis of extensive analyses and testing. The system was integrated in the national action plan. During the 2006 heatwave, the number of excess deaths was about 2,000. This was well below anticipated excess fatalities of 6,400, which had been estimated on the basis of meteorological statistics and mortality rates.

In the summer of 2007, Greece experienced the most damaging wildfires in its history. More than 70 people died and 270,000 hectares of forest, farmland, villages and infrastructure were severely damaged or destroyed. In response, the country acquired more heavy-lift helicopters, but structural and organisational problems in forest-fire control and prevention were not tackled. Perhaps not surprisingly, the wildfires in the following two years again went out of control. Early warnings were not given necessary consideration and Greece ended up requesting international help.

With thorough analyses of exposure, sensitivity, impacts and adaptive capacity resulting in a good understanding of critical vulnerabilities, effective ways of addressing them can be designed. Of crucial importance here is the timing of adaptation. Fankhauser *et al.* (1999) argue that with most benefits of adaptation still in the future, it is sensible to postpone most adaptation measures. There are some exceptions to this general conclusion, though. Fankhauser and Soare (2012) single out two major groups of adaptation measures that are worth implementing now: measures providing early benefits and measures that avoid costly lock-in.

Some adaptation measures may provide early benefits that will otherwise be lost if adaptation is postponed. Examples of such measures are improved efficiency of water supply and consumption, enhanced flood protection, measures to tackle heat stress, and protection and better management of environmental resources. These are often called win-win or no-regret measures. In terms of measures that avoid costly lock-in, climate-sensitive infrastructure investments with long lives come to mind, such as power grids, bridges and ports. Early studies estimate that the additional costs of making such investments climate-resilient could be in the range of 5 to 20 percent of total investment costs. Designing buildings to be climate resilient is another example. In some cases, buildings can be retrofitted cost-effectively to enhance their climate resilience, while in other cases it is more efficient to incorporate appropriate adaptation measures in building codes for new buildings. Planning and zoning is another area in which early adaptation measures are worth taking. Development in flood-prone areas and coastal zones and regions that are subject to water stress should be evaluated carefully not only in view of the current climate but also taking into account likely climate scenarios for the region.

2.5 Conclusion

Recognising that the literature on the economics of climate change is extensive and continues to grow fast, the review offered in this chapter is selective. Its aim is to highlight important issues for policymakers, such as the interplay between adaptation and mitigation. In particular, it has stressed that adaptation and mitigation are, in general, economic substitutes and this property is essential in the design of the optimal policy mix to address climate change. Thus, if climate change is smooth and gradual, the degree of substitution between adaptation and mitigation can be rather high. For instance, models imply that mitigation should be almost completely replaced by adaptation in a non-cooperative case, that is, when there is no effective international agreement to reduce greenhouse-gas emissions. In this context, this chapter has emphasised the capacity of adaptation to act as a strategic tool in climate change negotiations, thereby increasing the chances of reaching an agreement.

That said, adaptation and mitigation cannot fully substitute for one another, that is, it is never better to use only mitigation or only adaptation to address climate change. This is mainly due to two conceptual differences between adaptation and mitigation. First, it takes mitigation several decades before it becomes effective because of significant inertia in the carbon cycle. Adaptation measures, by contrast, typically become effective immediately or have relatively short investment lags. Thus, in the short to medium term, adaptation can be more effective in reducing the impact of climate change than mitigation can be in avoiding it. By contrast, in the long run, mitigation can prevent irreversible climate change or climate change that would demand drastic adaptation measures. Second, the existence of catastrophic climate risk or the perception of it weakens the scope for adaptation to substitute for mitigation. The reason is that only mitigation has the capacity to reduce catastrophic risk and, therefore, cannot simply be replaced by adaptation. This, of course, does not make trade-offs disappear, except in extreme cases, and they still play a non-negligible role in designing the optimal mitigation-adaptation mix.

Annex

The model of Bosello *et al.* (2012) is a dynamic optimal-growth model. The energy sector is specified in detail and the climate system is described by a climate module that feeds back into the economic system via a damage function. The model devotes special attention to adaptation. The model is global and the world is divided into 14 regions (*e.g.*, the United States, Western Europe, Eastern Europe, and transition economies), depending on economic, geographic, resource- and energy-sector features. It assumes no cooperation between regions and analyses the effects that catastrophic risk has on the optimal adaptation-mitigation policy mix. The risk of a climate catastrophe is endogenous in the model and it depends positively on the stock of greenhouse gases in the atmosphere.

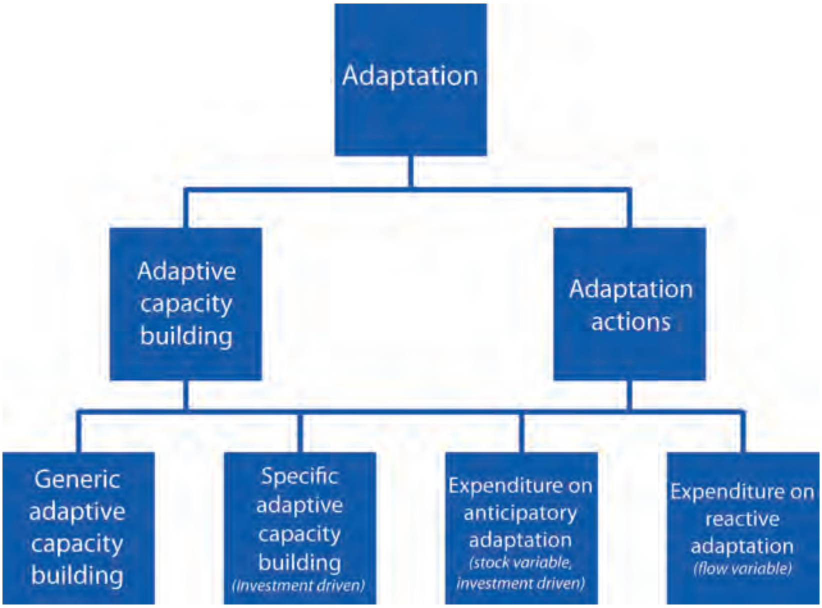
Adaptation and its components

Adaptation responses to climate change are categorised into two main groups each comprising two subgroups (see Figure A). The first main group *Adaptive Capacity Building* consists of *Generic Adaptive Capacity Building* and *Specific Adaptive Capacity Building*. The former involves efforts strongly attached to socioeconomic conditions and therefore the level of development of a region, whereas the latter focuses on investment directly for facilitating adaptation activity (*e.g.,* improvement of meteorological services, early warning systems, climate modeling, and so on). The second main group *Adaptation Actions* consists of *Expenditure on Anticipatory Adaptation*, on the one hand, and *Expenditure on Reactive Adaptation*, on the other hand. *Anticipatory Adaptation* includes all investment made in anticipation of climate change (*e.g.*, building a dyke) whereas *Reactive Adaptation* refers to action taken when climate impacts happen (*e.g.*, operating air conditioners more often and longer).

Stock and flow adaptation

In addition to differentiating between action and capacity building, it is useful to distinguish flow and stock adaptation. Flow adaptation, falling under the category of *Reactive Adaptation*, refers to actions such as heating and cooling and disease treatment. Stock adaptation, on the other hand, shifts the attention towards investment that aims at reducing the net damage of climate change and requires upfront investment that offers a stream of benefits well into the future. Being of a more anticipatory nature than flow adaptation,

Figure A: The adaptation tree in the AD-WITCH Model



Source: Bosello *et al.* (2012).

stock adaptation belongs to *Specific Adaptive Capacity Building* and *Anticipatory Adaptation Actions*. The distinction between flows and stock is made for a number of reasons. First, since stock adaptation requires investment, it is important to consider when adaptation costs and benefits occur, which discounting does. The discount rate has a decisive impact on the optimal policy mix of adaptation and mitigation. Second, the region where the response takes place is another parameter of importance, as poorer regions may find it more difficult to implement capital-intensive projects. Finally, identifying the investor is also important, with the public sector being more directly involved in stock adaptation than the private sector.

Gross damage and residual damage

The AD-WITCH model distinguishes between *Gross Damage* and *Residual Damage*. Adaptation surely reduces the level of damage from climate change, but does not alleviate it completely. In that sense, although *Gross*

Damage (*GD*) refers to the damage in absence of adaptation, when adaptation is present there is still *Residual Damage* (*RD*). *RD* is linked to *GD* and the level of adaptation (*ADAPT*) according to the following function (Agrawala *et al.* 2011):

$$RD_{j,t} = \frac{GD_{j,t}}{1+ADAPT_{j,t}}, \tag{1}$$

where *GD* in the absence of adaptation is exponentially linked to temperature changes, the subscript *j* represents the region, and *t* the time period.

Adaptation functions

The total level of adaptation as captured in (1) and presented in Figure A, is modelled as the combination of *Adaptive Actions (ACT)* and *Adaptive Capacity (ACP)*. The following *Constant Elasticity of Substitution (CES)* function describes the link between *ADAPT*, on the one hand, and *ACT* and *ACP*, on the other hand:

$$ADAPT_{j,t} = \left[\mu_j ACT^{\gamma}_{j,t} + (1 - \mu_j) ACP^{\gamma}_{j,t}\right]^{\frac{1}{\rho}}. \tag{2}$$

The two components of equation (2), namely *ACP* and *ACT,* are given by the following CES functions:

$$ACP_{j,t} = \left[\varphi_j SAC^{\gamma}_{j,t} + (1-\varphi_j) GAC^{\gamma}_{j,t}\right]^{\frac{1}{\gamma}} \tag{3}$$

where *SAC* and *GAC* correspond to *Specific* and *Generic Adaptive Capacity* respectively, as already demonstrated in Figure A and,

$$ACT_{j,t} = \beta_{1,j}\left[\beta_{2,j} FAD^{\rho}_{j,t} + (1-\beta_{2,j}) SAD^{\rho}_{j,t}\right]^{\frac{\beta_3}{\rho}} \tag{4}$$

where *FAD* and *SAD* represent *Flow (Reactive)* and *Stock (Anticipatory) Adaptation* respectively.

Adaptation costs

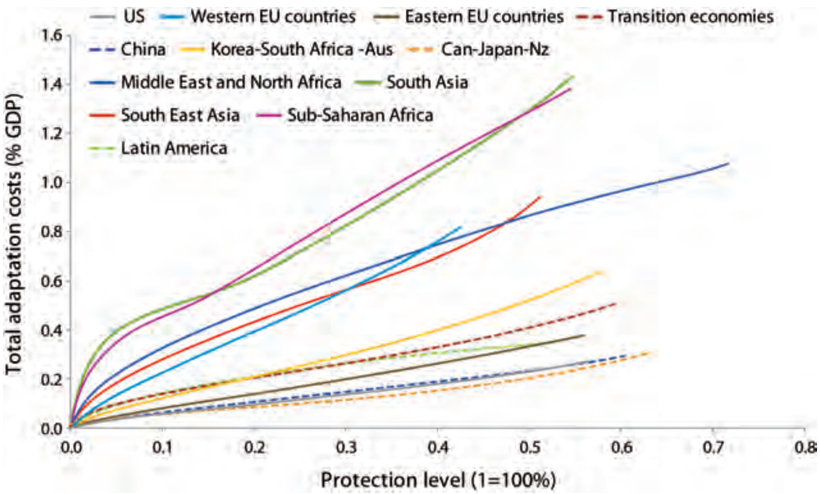
In order for the damages to be reduced, an *Adaptation Cost (AC)* has to be paid. In the AD-WITCH Model, this cost is given by the sum of expenditures on flow adaptation (FAD), stock adaptation (GAC and SAD) and specific adaptive capacity (SAC):

$$AC = FAD + GAC + SAD + SAC \tag{5}$$

Regional adaptation cost curves

Finally, in order to describe the ratio of gross damage avoided due to adaptation measures, the term *Protection Level* is used. Expressed on a 0-1 scale, a value of 1 implies that all gross damage is avoided and a value of 0.2 indicates that adaptation measures are able to offset climate damages by 20 percent. An *Adaptation Cost Curve* captures the relationship between adaptation expenditure and protection level. The AD-WITCH model features regional adaptation cost curves, reflecting the dependence of adaptation costs on regional damage and regional adaptive capabilities. Figure B shows regional adaptation cost curves, with the horizontal axis showing the protection level.

Figure B: Regional adaptation cost curves in the AD-WITCH model



Source: Bosello *et al.* (2012).

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CHAPTER 3

Boosting climate investment

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Chapter at a glance

This chapter develops and applies a framework for analysing why there might be too little climate investment and how to boost it. A key feature of this framework is the distinction between primary and secondary reasons for underinvestment, and between primary and secondary solutions to underinvestment problems. Climate investment as understood here comprises investment directly aimed at mitigating greenhouse-gas emissions and at adaptation to climate change. Investment in upstream activities – such as developing better engines, fuel cells, and climate-resilient materials – are not explicitly considered. At the centre of the analysis is the quest for economic efficiency, though in a few places distributional concerns get a mention. A summary of sections 3.2, 3.3 and 3.4 follows. For a narrative of the main messages see section 3.5 of this chapter.

Section 3.2: Reasons for underinvestment in climate-change mitigation and adaptation

- To find an efficient climate policy mix, it is crucial to identify the most important of the multiple failures and barriers hindering climate investment.

- The climate-change externality of greenhouse-gas emissions and the global collective action problem of cutting them are primary barriers to investment in avoiding, capturing and sequestering emissions.

- Informational and behavioural problems are primary barriers to investment in energy savings.

Section 3.3: Tackling underinvestment – a generic view

- To find an efficient climate policy mix, it is also essential to distinguish between primary and secondary solutions to underinvestment problems. Primary solutions address the causes of underinvestment while secondary solutions merely reduce the underinvestment.

- Most primary solutions do not require fiscal resources; they may even generate funds. By contrast, secondary solutions often require fiscal resources. This generally should favour primary solutions, and makes them especially attractive in times of tight fiscal constraints.

Section 3.4: Tackling underinvestment – a close up of climate investment

3.4.1: Investment in low-carbon technologies and CCS

- Carbon pricing (*i.e.* cap-and-trade or a carbon tax) is a primary solution to underinvestment; policy measures such as subsidies, command-and-control and the creation of markets for specific technologies are not.

- Inefficiencies can result from policy interaction between cap-and-trade and other climate policy measures.

- Two steps would fundamentally enhance the efficiency of European climate action: first, bringing more emissions under the EU emissions trading system and ensuring its long-term existence; second, eliminating harmful policy interaction.

3.4.2: Investment in residential energy savings

- Informational and behavioural problems are primary barriers to investment. Primary solutions comprise information campaigns, energy labelling and passes, 'nudge' and time-bound support for developing markets for energy services.

- Subsidising investment in energy savings is a secondary solution, a drain on fiscal resources and prone to free-rider problems.

- Not knowing the energy-savings gap is an obstacle to ambitious standards and mandatory savings – even if the latter are tradable.

3.4.3: Investment in adaptation

- Unintended consequences of well-intended government intervention might result in too little private investment in adaptation.

- Good policies include zoning restrictions, building codes, mandatory insurance and limits to government help in climate-risk events.

- To ensure efficient public investment in adaptation, communities that benefit from it need to pay for it. This will also help to prevent public investment from crowding out more efficient private adaptation.

- Pro-growth policies are perhaps the best adaptation investment that societies can make, given the positive link between economic growth and societies' adaptive capacity.

3.1 Introduction

A chapter on boosting climate investment assumes two things: first, investment is not as high as it should be and, second, there is a norm specifying how high it should be. The norm economists typically use is the level of investment that would result in a perfectly competitive market economy, that is, an economy that allocates resources efficiently without the need for policy intervention. This is not the place to delineate the features of such an idealised, perfect economy,[28] but some of them become clear when considering the reasons why climate investment falls short of what it would be in a perfect economy. Climate investment as understood here comprises investment directly aimed at climate-change mitigation and at adaptation to climate change. Investment in upstream activities – such as developing more fuel-efficient engines, fuel cells, and climate-resilient materials – are not explicitly considered. That said, underinvestment in climate-change mitigation and adaptation stifles investment in upstream activities and, by extension, boosting the former encourages the latter.

All possible reasons for underinvestment can be grouped into four broad categories, though the demarcation lines between them are not clear cut. All reflect a deviation of real-world economies from perfect ones. First, there are market failures. To be clear, in the jargon of economists, market failures are shortcomings inherent in market mechanisms, but not to incompetence, wickedness, or possibly other failures on the part of market participants. Arguably the most prominent market failure is the climate-change externality of greenhouse-gas emissions – carbon emissions for short. Unless that problem is tackled, there is overuse of high-carbon sources of energy and, for a given demand for energy, underinvestment in low-carbon technologies. The provision of public goods, such as protection against rising sea levels, is another area where markets fail to provide what people want. There are many more such areas.

The second category comprises reasons for underinvestment that reflect so-called behavioural failures, that is, systematic deviations from self-interested and perfectly rational choices. To be clear again: although behavioural failures might suggest incompetence on the part of decision makers, they are merely meant to describe outcomes that are inconsistent with self-interest and rationality – two key assumptions of traditional economics. In essence, behavioural failures in the realm of climate change might lead people to opt for less climate-change mitigation and adaptation than they truly want.

Third, one can think of a category that comprises all other underinvestment explanations that are due to gaps between real-world economies and perfect ones. For ease of reference, explanations in this category are labelled here 'other barriers to investment'. One example is imperfect competition due to a limited number of suppliers – in energy markets, for instance.

Finally, policy failures might cause too little climate investment. They might come in different varieties. For the purpose of this chapter, however, it is useful to employ a rather narrow concept and focus on missing, insufficient, and unwise government intervention aimed at promoting investment in mitigation and adaptation.

Moving on from reasons for underinvestment to the investments that might be affected, it is useful to categorise the many climate-change mitigation and adaptation investments. To start with mitigation, one can distinguish investment aimed at reducing (i) the use of energy; (ii) the carbon content of it; (iii) non-energy emissions from industrial processes; (iv) emissions from land use, land-use change and deforestation; and (v) the stock of carbon in the atmosphere.[29] These five groups are all-inclusive as they cover all possible mitigation investments.

There are many ways in which adaptation investment could be classified (as discussed in chapter 2), but from a policy perspective an obvious distinction is between private and public investment. In real-world economies, investment in adaptation is bound to be sub-optimal for two reasons. First, market failures, behavioural failures and so on might prevent private investment from reaching the level that self-interested and rational individuals aim for. Second, the same failures might create a gap between investment by individuals and the investment that is in the interest of society as a whole, and, if they do, there is a rationale for public investment – municipal flood-protection is one example.

Putting the pieces together, there are four types of reason for underinvestment in mitigation and adaptation, five types of mitigation investment, and two types of adaptation investment. One purpose of this chapter is to present a taxonomy that maps the reasons for underinvestment to different types of investment in mitigation and adaptation. The motivation is to offer a coherent approach to identifying the most important of the multiple failures and barriers that hinder climate investment. To illustrate, the most important reason for underinvestment in low-carbon sources of energy is the climate-change externality. While this is well-known, there remains much to explore, and this will be done in section 3.2.

Another purpose of this chapter is to present – in section 3.3 – a taxonomy that maps reasons for underinvestment to possible policy tools and, more importantly, to identify the tool most suitable for addressing the underinvestment problem. For a preview of the most obvious mapping, think of carbon pricing to address the climate-change externality, information and awareness campaigns to help improve energy users' choices, and public investment in flood protection.

Once we have a taxonomy that maps reasons for underinvestment to different types of climate investment (section 3.2) and a taxonomy that maps reasons for underinvestment to policy tools (section 3.3), we also have a conceptual framework for analysing for each conceivable climate investment why there might be too little of it and how to boost it. Section 3.4 applies this framework to investment in residential energy savings (aimed at reducing the use of energy), low-carbon technologies (aimed at reducing the carbon content of the energy used), and private and public adaptation.

Before setting off it is important to note that at the core of the following analysis is the quest for economic efficiency. Having said this, in a few places it is pertinent to address distributional concerns. It is also useful to recall from chapter 1 that this report takes an advanced countries' perspective and does not analyse challenges for developing countries. Equally important, while it should be immaterial whether or not economically efficient ways of boosting climate investment require fiscal resources, the fiscal dimension cannot be ignored in times of, not only climate change, but also sovereign debt crisis. The good news is that there is no conflict between well-targeted climate policy and fiscal consolidation.

3.2 Reasons for underinvestment in climate-change mitigation and adaptation

This section surveys key reasons for underinvestment in mitigation and adaptation. Table 1 guides the narrative that follows: columns show the reasons – that is, market and behavioural failures, other barriers to investment, and policy failures – while rows list the climate investment that might be affected; table entries are labelled *P*, *S*, and *N*, respectively, indicating reasons of primary (*P*), secondary (*S*) and no (*N*) or little importance. The degree of importance attached to a particular reason reflects judgment rather than hard science. With this duly noted, the following taxonomy emerges.

3.2.1 Mitigation

Low-carbon technologies

Externalities

The most prominent market failure hindering investment in low-carbon technologies is the negative climate-change externality – one of many possible environmental externalities. More precisely, high-carbon technologies – in energy, transport, industrial processes and so on – cause external damage and unless this is internalised, such technologies have a competitive advantage over low-carbon alternatives.[30] In addition to the climate-change externality, there are other environmental externalities which, unless internalised, bias the choice of technologies against low-carbon ones. In particular, there are external damages resulting from emissions of sulphur dioxide, nitrogen oxide and other air pollutants. That said, low-carbon technologies come with their own negative externalities – visual intrusion and noise associated with wind farms, for instance. On balance, it is fair to conclude, however, that uncompensated environmental externalities put low-carbon technologies at a considerable disadvantage and, as a result, there is too little investment in low-carbon technologies. In sum, environmental externalities – including the climate-change externality – can be considered a primary reason for too little low-carbon investment.

The next column in Table 1 refers to positive technology externalities, that is, technological knowledge created by one firm spilling over – free of charge –

Table 1: Mapping investment barriers to different types of climate investment

	Market failures, behavioural failures, policy failures, & other investment barriers							
	Externalities			Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers	Policy failures
	Env't (–)	Tech (+)	SoS (–)					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mitigation								
Low carbon technology	*P*	*S*	*S*	*P*	*S*	*N*	*P*	*
Energy savings	*S*	*S*	*S*	*N*	*P*	*P*	*N*	*
REDD	*P*	*N*	*N*	*P*	*N*	*N*	*N*	*
Sequestration	*P*	*S*	*S*	*P*	*S*	*N*	*P*	*
Adaptation								
Private	*N*	*S*	*N*	*N*	*S*	*S*	*N*	*
Public	*N*	*S*	*N*	*N*	*S*	*S*	*N*	*

P = Barrier of primary importance for the investment at hand.
S = Barrier of secondary importance for the investment at hand.
N = Barrier of no (little) importance for the investment at hand; or not analysed in detail.
* = Policy failures are potentially very important and, thus, merit a visual representation in the table. However, the grading *P*, *S*, and *N* is not useful for policy failures as it is always important to correct them.

Env't stands for environmental externalities, notably the climate-change externality of greenhouse-gas emissions. *Tech* stands for technology externalities, *i.e.* knowledge spillovers. *SoS* stands for security-of-supply externality. The + sign and the – sign in columns (1) to (3) indicate, respectively, positive and negative externalities.

to other firms. As the table indicates, this is a positive externality. It makes sense to distinguish two broad types of knowledge. One comes with the creation and diffusion of new technologies. There are various reasons why markets might fail in creating and diffusing new technologies as much as is desirable from society's viewpoint. But as discussed in Riess and Välilä (2006), for instance, this type of market failure is not as grave as often feared and markets are quite innovative in overcoming their own failures. That said, if they do fail, firms underinvest in the creation of new technologies and whatever innovation there is might not disseminate through the economy as much as it could.

The second component of knowledge does not concern the creation and diffusion of new technologies. Rather, it has to do with improvements to new technologies resulting from so-called learning and experience effects. In contrast to the knowledge associated with creating and diffusing new technologies, technological knowledge due to learning and experience happens at the commercialisation stage in the lifecycle of technology developments. Kolev and Riess (2007) review in greater detail the nature of learning and experience effects, and the rationale for economic policies possibly deriving from them. Suffice to note here that when firms start using a new technology, they increasingly learn how to use it better and, as a result, experience a decline in production costs. The problem is, however, that for a variety of reasons learning and experience might not go as far as they should from society's viewpoint. At present, this type of technology externality possibly hinders most renewable sources of electricity, with the exception of hydro and wind energy in favourable locations.

A sensible conclusion is that technology externalities can hinder low-carbon investment, but compared to environmental externalities, they are probably of secondary importance. In this context, it is also vital to bear in mind that technology externalities are not particular to low-carbon technologies but also affect a host of other innovative endeavours.

The last externality featuring in Table 1 is the security-of-supply (SoS) externality. Similar to the negative environmental externality associated with the use of fossil fuels, there is concern that fossil-fuel use is too high and, by extension, investment in low-carbon technologies is too low. The negative security-of-supply externality has two dimensions: price and quantity (see, for instance, Bohi and Toman, 2006; and Mulder *et al.*, 2007).

The economic logic underlying the price dimension is intricate. For a start, the negative security-of-supply externality does not arise from the use of fossil fuels *per se* but from the use of imported fuels. Things are even more complex: the externality is not because fuels are imported, but because they are imported from countries that have market power. The concern, then, is that individual consumers do not account for the effect that their consumption has on all consumers' dependency on suppliers with market power and the possibility that an increase in import dependency increases the incentive of suppliers to exploit their power. Three insights follow from this logic: first, use of domestic fossil fuels does not give rise to a negative security-of-supply externality; second, neither does importing fossil fuels from a diverse set of countries; third, low-carbon technologies might come with a negative security-of-supply externality, too, if an increasing share of low-carbon energy is sourced from a narrow set of countries – as could be the case with the envisioned solar electricity imports from North Africa, the Middle East and the Gulf region.

The economic logic behind the quantity-related security-of-supply externality seems less complicated. The notion is that the social cost of a physical supply interruption exceeds its private cost, with the physical interruption possibly due to non-availability of energy, or a breakdown of the supporting transport and distribution infrastructure. This kind of externality can be due to supply interruptions at home or abroad. For it to indirectly hinder low-carbon investment, one must implicitly assume that high-carbon energy resources are more susceptible to this externality than low-carbon resources.

While the security-of-supply externality cannot be discarded, it clearly ranks second to the environmental externality. This is also because an energy system increasingly based on intermittent low-carbon sources of energy – such as wind and solar – comes with its own security-of-supply challenges. Attaching secondary importance to the security-of-supply externality is not at odds with the high importance security of supply receives in the political debate. In fact, the political rationale for defining and ensuring security of supply links only weakly with the market-failure rationale outlined here. From a political perspective, security of supply typically means a stable supply of energy at affordable prices. As Mulder *et al.* (2007) explore, there have been only a few incidents since the early 1950s when energy security so defined was in doubt.

Before turning to public goods, note that there might be externalities other than those explicitly mentioned in the first three columns of Table 1 – examples will be given below when discussing adaptation. But for low-carbon investment, Table 1 covers the essential ones.

Public goods
Public goods have two defining features. One is non-excludability, meaning

that non-paying users cannot be excluded from consuming them. The other is non-rivalry, meaning that the consumption of non-paying users does not diminish the benefit of paying users. In these circumstances, nobody is willing to pay for these goods and, as a result, markets fail to provide them. The mirror image of a public good is a public 'bad': non-excludability implies that once there is a public bad, it damages everybody not only those responsible for it; non-rivalry implies that the damage to an individual sufferer does not lessen with an increase in the number of sufferers.

The climate-change externality discussed above can be approached, too, from the angle of the public-good market failure. Emitting carbon can be considered a global public bad and cutting emissions a global public good. From a global perspective, the public-good market failure stifles collective action and, thus, suppresses low-carbon investment and other mitigation efforts. The reasons for this have been set out in chapter 2.

Information problems and uncertainty

Information problems come in different varieties. Conceptually, it makes sense to distinguish between two. The first is asymmetric information, which is a genuine market failure; loosely put, it arises when one party to a transaction knows more than the other and when it is impossible for the better informed party to credibly pass on its information to the other party.[31] The second is imperfect information, which simply reflects a gap between what people know in real-world economies and what they are assumed to know in perfect ones. The second variety includes uncertainty, that is, imperfect information about the future.

To see how information problems might result in too little low-carbon investment, consider the case of a new, innovative renewable technology that has been successfully tested and is ready to enter its commercialisation phase – take offshore wind farms as an example. During this phase, the technology might not be profitable from the very start, but sponsors of this technology expect it to become profitable once experience of this new technology has been acquired and thus costs have been driven down. To distinguish information problems from the technology externalities discussed above, assume that the knowledge gained through learning and experience can be fully appropriated by first movers. In these circumstances, information asymmetry between the sponsors of this technology and potential lenders might make it hard to mobilise finance and, as a result, commercialisation of a promising technology does not take place or is delayed. This is a case where asymmetric information results in capital market failures.

Imperfect information might exacerbate the problem. As an example of imperfect information, consider the shortcomings in assessing the profitability of the new, innovative renewable technology. The standard approach to assessing profitability is discounted cashflow analysis. An investment is profitable if its net present value, calculated at the weighted average cost of funds, is positive. A salient feature of a standard analysis is that it does not value options that an investment today might create for tomorrow. This is fine for appraising investments that do not create options, but it misses valuable information on investments that do. Options resulting from venturing into commercialising new renewables – low-carbon investment in general – are manifold, as will be further explored in section 3.3. The point here is that without adequately valuing options created by today's investment opportunities, their profitability might be underestimated by project sponsors or their creditors.[32] It follows that promising opportunities might be overlooked or do not get the finance they deserve.

That said, while the effects of information problems on low-carbon investment are clearly not trivial, it is sensible to judge them only of secondary importance – notably compared to the far more relevant climate-change market failure.

Behavioural failures

Traditional economics assumes that people are self-interested and choose rationally. Behavioural economics – a still relatively new branch of economics that incorporates lessons from psychology – has challenged this approach by showing how people frequently make choices that deviate from the assumption of both self-interest and rationality even when they are well informed. From the perspective of traditional economics, seemingly irrational choices observed in reality and explained by behavioural economics are labelled behavioural failures.[33] Such failures possibly influence decisions of consumers, employees, investors, policymakers, firms, and so on. That said, competition among firms reduces the scope for behavioural failures as making them would undermine the viability of firms. Against this background, it is reasonable to conclude that behavioural failures contribute little to explaining underinvestment in low-carbon technologies, the bulk of which is carried out by firms. By contrast, behavioural failures contribute to explaining people's reluctance to invest in seemingly profitable energy savings, which will be discussed below.

Miscellaneous market failures and barriers to investment

This category is a 'catch all', comprising all other market failures and barriers to climate investment.[34] Three of them merit attention in the context of low-carbon investment. For one, there is the natural-monopoly market failure, which – unless corrected – hampers investment in electricity transmission networks, and insufficient network investment hampers investment in electricity generation. In principle, this market failure impedes investment in power plants in general, but investment in renewable capacity is especially hard hit given the spatial distance between where renewable electricity can be produced cheaply and where consumers need it.

Given the link between investment in networks and renewables, there is the more general challenge of overcoming a chicken-and-egg problem: without or with too little investment in networks, there will be no, or too little, investment in renewable capacity and *vice versa*.[35]

Continuing with the electricity sector, another barrier to investment in renewable electricity might be a strong market position of incumbents and their traditional focus on fossil and nuclear energy. While the difficulty of replacing incumbent nuclear energy with renewable electricity is of no concern from a climate-change perspective, an uneven playing field that favours incumbent fossil energy over new entrants planning to generate electricity from renewable resources does pose a problem.

All in all, the natural-monopoly characteristic of networks, the challenge of coordinating investment in networks and power plants, and the presence of dominating incumbents can easily result in underinvestment in both networks and renewable generating capacity, and it seems justified to consider them primary obstacles to low-carbon investment.

Policy failures

In the public finance literature, such as Musgrave and Musgrave (1989), the complement to market and behavioural failures is government failure. Similar to market and behavioural failures, government failure is not about easily avoidable mistakes – those of bureaucrats, for instance. Rather, it concerns problems inherent in direct democracy, representative government, decentralised government, and in the public supply of goods, services and regulation. Problems of this kind will not be pursued here. Rather, what will be discussed is missing, insufficient, and unwise government intervention aimed at boosting climate investment. In a sense, it is about those policy failures that in principle are easy to avoid.

With the scope of the analysis so defined, it makes little sense to discuss policy failures before having first presented polices to overcome market and behavioural failures and other barriers that hinder low-carbon investment (and other climate investment). Yet, one policy failure – still relevant even in advanced economies – can be mentioned upfront: the implicit or explicit subsidisation of energy consumption and fossils fuels. EEA (2004) reports EU fossil-fuel subsidies of €22 billion a year in 2004. For OECD countries, OECD (2011) reports subsidies of this nature of $45-75 billion a year in 2005-10. Arguably, dismantling such policies should come first in attacking climate change.

To find out how to best boost climate investment it is crucial to distinguish between important and unimportant market failures, behavioural failures, and other barriers – and this is the purpose of grading these problems as *P*, *S*, and *N*, respectively. It makes little sense, however, to grade policy failures in a similar way. Their relevance is context specific, but when they are made it is of primary importance to avoid them. Section 3.4 will shed light on policy failures in specific contexts. Nonetheless to signal the potential importance of policy failures, Table 1 includes them. In any event, without them, a taxonomy of obstacles to climate investment would surely be incomplete.

Energy savings

Externalities

The climate-change externality affects energy consumption and, by extension, investment in energy savings only indirectly. To see why, imagine a zero-carbon world. In this world, using energy does not cause damages, and there is thus no climate-change reason to save energy. Consider the other extreme, a world with only fossil energy resources. Unless their climate-change externality is internalised, energy prices will be sub-optimally low, energy use too high, and efforts to save energy muted. Picture, then, the real world in between, where there are near zero-carbon energy resources and fossil fuels. In this situation, a switch from fossil fuels to zero-carbon energy reduces carbon emissions regardless of how much energy is consumed. And if policies make emitters fully internalise the climate-change externality, the ensuing amount of energy use is optimal from a climate-change perspective. In sum, energy use *per se* does not cause external damages – it is the use of fossil fuels. For the climate, what matters is to switch from fossil fuels to near zero-carbon energy rather than to save energy *per se*.

Two caveats come to mind, however. First, the scope for substituting near zero-carbon energy for fossil energy is not perfect. In a number of industrial applications, for instance, natural gas cannot be replaced. Second, near zero-carbon energy comes with negative environmental externalities, too, such as noise and visual intrusion of wind farms, and without internalising these externalities too much energy is consumed. In sum, however, it seems reasonable to conclude that environmental externalities play only a secondary role, if at all, in hindering investment in energy savings – as the excerpt from Table 1 below indicates.

	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers	Policy failures
Energy savings	*S*	*S*	*S*	*N*	*P*	*P*	*N*	*

Technology externalities could be considered as relevant for investment in energy savings as for low-carbon investment. That said, both types of technology externalities (that is, spillovers resulting from the creation and diffusion of new technologies, on the one hand, and from learning and experience effects on the other hand) typically are not mentioned as much in the context of energy savings as in the context of low-carbon technologies.

The security-of-supply externality hinders investment in energy savings as much (or as little) as investment in low-carbon technologies. That is, when deciding how much energy to use, individual consumers are not bothered by the effect their consumption has on all consumers' dependency on suppliers with market power or on the probability of physical supply interruptions. In any event, similar to the, at best, indirect link between the use of energy and the climate-change externality, it is the use of imported gas and oil rather than the use of energy *per se* that might create a security-of-supply externality.

Public goods
The public-good market failure does not apply to energy savings. Anyone investing in energy savings can exclude anyone who has not invested from the savings made. And the savings made by those who invest cannot be shared with others without reducing the savings accruing to the investor.

Information problems and uncertainty
Information problems are perhaps the key reason why seemingly profitable investments in energy savings do not see the light of day – the money 'left on the floor' – even if energy users are made to pay energy prices that incorporate all externalities.[36]

As above, it is useful to distinguish two broad types of information problems – imperfect information and asymmetric information. To start with imperfect information, users might lack information on their energy consumption, which could reflect a lack of information *per se* (*e.g.* poor information content of energy bills) or failure to collect and process such information – for instance, because it costs time to gather and process such information. Moreover, users may lack information on the most promising opportunities to save energy – energy-efficient heating systems, better thermal insulation, improved management of energy consumption, fuel-efficient cars, and so on. Again, there could be an information problem *per se* or a problem of seemingly too costly information gathering and processing. This also applies to a third variant of imperfect information: inadequate information on the cost, performance, and reliability of energy-saving technologies – all crucial elements for deciding whether investments in energy savings are worthwhile. This variant of imperfect information leads to asymmetric information as a factor behind the underinvestment in energy savings.

Suppliers of energy-saving technologies inevitably know more about the quality of the technologies they offer than buyers. The trouble is that suppliers cannot perfectly transfer their knowledge to buyers. As a result, demand for and investment in energy-savings is not as high as it could be. Equally important, asymmetric information hinders high-quality technologies more than low-quality ones and, as a result, supply of the former is lower than it could be.

Asymmetric information is also behind the so-called split-incentive problem, which impedes investment in energy savings in the housing sector, for instance. To illustrate, all other things being equal, the higher its energy efficiency, the higher the value of a house. While owners and potential sellers of high energy-efficient houses know the quality of their property, it is not easy for potential buyers to understand and value the energy savings resulting from living in high energy-efficient houses. As a result, bids for houses will be low, thus stifling incentives for investing in energy savings. The same problem arises with rented accommodation. In this case, tenants find it difficult to ascertain the energy-saving potential claimed by landlords and reflected in the rent and, thus, landlords have little incentive to improve the energy efficiency of their property.

The split-incentive problem and the asymmetric information behind it can also be approached from the perspective of tenants who consider making the accommodation they live in more energy efficient. Of course, they would only invest if they are certain that they remain tenants long enough to fully reap the return on their energy-efficiency investment or, alternatively, if they could enter into contracts with landlords to be compensated for the outstanding value of their investment should they leave the accommodation ahead of time. But contracts of this nature suffer from the same asymmetric information problem previously described for the housing market, only it is now the landlord who could find it hard to properly assess the value of the investment that tenants claim to have made.

In sum, demand for investment in energy savings is bound to be lower than it would be with symmetric information. But that is not all: there could also be a lack of finance for whatever demand there is. For a start, since asymmetric information tends to make the supply of finance smaller than it would be in a perfect world, not all of the planned investment in energy savings materialises. In this context, it is often observed that finance is particularly scarce, expensive or both for low-income households. Although this is true, it might simply reflect the higher risk of lending to the poor rather than a market failure. And then, while not reflecting an asymmetric information problem, finance for investment in energy savings by firms could be sub-optimally low as firm managers typically attach lower strategic value to energy savings than to other investment opportunities.[37]

To summarise, information problems are of primary importance for underinvestment in energy savings.

Two more informational problems must be explored: uncertainty and so-called hidden costs. They are frequently considered barriers to investment in energy savings though closer inspection shows that they often reflect perfectly rational behaviour, not requiring a policy response.

Like any investment, investing in energy savings is surrounded by uncertainties. Key uncertainties specific to investment in energy savings concern the price of energy saved and the performance of energy-saving technologies. If investors perceive these uncertainties as high (low), they discount the benefits of their investment at a high (low) rate of interest, which reduces (increases) chances that a potential investment is found valuable. In addition, uncertainties affect the choice of technology: high uncertainties and, thus, discount rates make investments with large upfront costs (and potentially big energy savings) less attractive than investments with small upfront costs and potentially little energy savings. There is nothing wrong with this outcome unless investors misperceive uncertainties and apply unjustifiably high discount rates (in part also due to behavioural failures discussed below). Should that be the case, there is an argument for publicly funded information programmes and projects that demonstrate the performance of energy-saving technologies. Note, however, that misperception of uncertainties and possibly too high discount rates might affect investment in general and only if investment in energy savings suffers more than the rest, could one argue for a dedicated policy intervention.

There is another effect of uncertainty that discount rates typically do not capture, but this one, too, does not call for a policy response. Most of today's investment opportunities can be carried out tomorrow. That certainly applies to investment in energy savings. But with the option to delay, it might not be worthwhile to invest today even if the investment's net present value is positive. Obviously, delaying good investments makes sense if their profitability is even higher when carried out later.[38] This could be the case if there are reasons to expect lower investment cost and/or uncertainty about the performance of the technology. For investments in energy savings, it might indeed be realistic to hope that technological uncertainty will resolve as and when experience of the underlying technology has been gained. In essence, delay is rational if the energy savings forgone while waiting are lower than the benefits from a fall in investment cost and/or more certain energy savings.

Turning to hidden costs, their salient feature is that they are hidden only to outside observers. Potential investors are aware of them and find them important enough to discard investment opportunities that appear worthwhile to outside observers.[39] Hidden costs of more energy-efficient choices are manifold, including loss of utility (*e.g.* from fluorescent light bulbs in lieu of incandescent ones) and extra costs of implementing and maintaining more energy-efficient choices (*e.g.* new light fittings and lamps for fluorescent light bulbs).

To conclude, uncertainty and hidden cost are a good explanation of why people disregard seemingly promising energy-saving opportunities. In contexts where uncertainty appears to unduly bias decisions against investing in energy savings, the true culprit seems to be informational and behavioural problems rather than uncertainty *per se*. This leads to a discussion of why behavioural failures might stifle investment in energy savings.

Behavioural failures

Two broad types of behavioural failures can be distinguished. To begin with, the 'prospect theory' posits that people choose with specific benchmarks in mind and worry more about potential losses than gains. In the case of investment in energy savings, a natural benchmark is the status quo, and when people attach greater weight to potential losses than gains associated with departures from things as they are, there is bias towards leaving things as they are.

The second type of behavioural failure is bounded rationality, which explicitly acknowledges that people cannot make perfectly rational choices because they lack time, awareness and the capacity to adequately process information. Given these constraints, people often apply rules of thumb that unintentionally sort out profitable ways of saving energy. To illustrate, people might screen energy-saving options based on their most visible attributes – their upfront cost, for example – and rule out options with upfront cost above a certain threshold. This might also be due to financial constraints that limit the amount of funds available. As a result, lifecycle cost-benefit analyses are performed, if at all, only for the remaining options, which do not necessarily include the most profitable ones.

Overall, one can think of behavioural failures that result in a level of energy-saving investment that is lower than the investment following from self-interested, perfectly rational choices. A couple of qualifications are worth making, however. First, while evidence suggests that behavioural failures indeed suppress investment in energy savings, their magnitude and the magnitude of the policy response needed to correct them is not well understood. Second, *a priori* there is no reason to rule out behavioural failures that result in too much rather than too little investment – behavioural failures might bias choices in either direction. Third, from a policy perspective, there is no question whether or not market failures should be corrected – though it is always pertinent to ask whether government intervention can correct them at reasonable cost. In essence, the aim of government intervention is to help people pursue the utility- and profit maximisation objectives they are assumed to have. By contrast, with behavioural failures, it is not obvious at all whether governments should intervene. This is because government intervention aimed at correcting behavioural failures assumes that people ought to make self-interested and rational choices – a view one may not necessarily subscribe to (see Aldred 2009, for instance). In essence, to justify government intervention in the case of behavioural failures, one needs to assume that people want to be self-interested and rational utility maximisers – notwithstanding some evidence that they are not.

Reduced emissions from deforestation and forest degradation (REDD)

Land use, land-use change, and forestry – LULUCF in climate-change jargon – can result in greenhouse-gas emissions, but it can also remove greenhouse gases from the atmosphere. In the EU, LULUCF currently leads to a removal of greenhouse gases, making EU net emissions smaller than they would be without LULUCF. Globally, however, LULUCF is estimated to be a net contributor, accounting for 15-20 percent of greenhouse-gas emissions, which is almost at par with emissions from industry and ahead of emissions from transport.

The bulk of LULUCF emissions is due to deforestation and forest degradation and, thus, reduced emissions from deforestation and forest degradation – REDD in climate change jargon – hold considerable potential for cost-effective climate change mitigation. To illustrate, estimates suggest that about half of current emissions from forest clearing can be avoided at an average cost of less than €20 per tonne of carbon dioxide. This compares favourably to the abatement cost associated with many renewables and carbon sequestration, which explains why REDD is often considered a low-hanging fruit (Boucher, 2008; Myers Madeira, 2008; and CBO, 2012).[40]

But why is there too much forest clearing and, by extension, why is *REDD* vastly underused in climate-change mitigation? There are two main factors, destructively interacting and reinforcing one another in many places. First, decisions to clear forests – to make way for traditional farming, cattle, livestock feed production, biofuels and so on – are blind to the external climate damage associated with the release of carbon dioxide and other greenhouse gases. There is then too much forest clearing compared to a situation where those benefiting from it would have to pay for the external damage they cause. Second, property rights on forests might not be defined at all or ill-defined – leading to the well-known tragedy of the commons that results in an excessive use of the commons, forests in this case.[41]

From a climate-change perspective, the external damage of emissions from forest clearing is the same as the one associated with the use of fossil fuels. Likewise, reducing emissions from deforestation and forest degradation is similar to substituting low- for high-carbon technologies in energy, industry and transport. This explains why Table 1 (for convenience see the extract below) shows the environmental externality as a primary obstacle to REDD. The same logic explains why the global public-good market failure is listed as a primary reason for too little REDD.

	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers	Policy failure
REDD	*P*	*N*	*N*	*P*	*N*	*N*	*N*	*

The remaining two externalities – the technology externality and the security-of-supply externality – do not apply to REDD. While other failures and barriers might have some relevance, they can probably be safely ignored. That said, there is considerable scope for policy failures, as shown by Boucher (2008), for instance.

Carbon sequestration

Carbon sequestration – that is the capture and storage of carbon dioxide – could be in forests, oceans and geological structures. With forest sequestration, just as forest clearing releases carbon, so can afforestation and other land-use changes absorb it from the atmosphere. The market failures standing in the way of forest sequestration are the same as those resulting in excessive forest clearing – that is the main obstacles to investment in forest sequestration are the positive environmental externality of removing carbon from the atmosphere and the global public-good aspect of doing it.

This is true, too, for ocean sequestration, which can take two broad forms. One is to inject liquid carbon dioxide into the deep ocean, while the other is to enhance the natural oceanic uptake of carbon dioxide by, for instance, adding micronutrients to promote algal growth. Two differences to forest sequestration are worth mentioning. First, ocean sequestration can be high-tech and, thus, technology externalities might arise – though they are unlikely to be more pronounced than they are for innovative endeavours unrelated to climate change. Second, ocean sequestration, while capturing carbon, comes with its own environmental challenges, notably ocean acidification.

Geological sequestration is the sink typically foreseen for carbon dioxide emissions from fossil fuel power plants and industrial processes, such as cement manufacturing. Carbon dioxide is prevented from reaching the atmosphere by applying a technology called carbon capture and storage – CCS for short.[42] Possible storage locations include old oil wells, depleted natural gas fields and saline aquifers. This technology is foreseen as playing an important role in Europe's strategy to reduce its carbon emissions (European Commission 2011a). This sets this technology apart from ocean and forest sequestration (and REDD) where the potential is largely in international waters and developing countries – though Europe and other developed countries will be crucial in helping to exploit that potential.

	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers	Policy failure
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sequestration	*P*	*S*	*S*	*P*	*S*	*N*	*P*	*

The obstacles to investment in electricity and industrial production that feature CCS are similar to those obstructing low-carbon investments:

- Unless internalised, the external damage of producing without carbon capture puts CCS at a considerable disadvantage (column 1 in Table 1).

- Technology externalities hinder CCS commercialisation (column 2).

- As for the security-of-supply externality (column 3), a sensible assessment is that CCS coal-fired power plants reduce dependence on foreign oil and gas producers with market power as much as investment in renewable energy. In fact, since electricity from such plants is less intermittent than renewable electricity, the former might contribute more than the latter to energy security.

- Global public-good characteristics of avoided carbon emissions result in too little CCS (column 4).

- Information problems may result in underestimating the viability of CCS and a lack of finance (column 5). That said, finance constraints due to asymmetric information are probably less relevant since CCS is typically pursued by large, established firms rather than small, new ones, which try to establish themselves as producers of renewable electricity.

- Behavioural failures are probably as irrelevant for CCS as for low-carbon investment (column 6).

- Interdependence between investment in electricity generation and transmission as well as the presence of dominant electricity producers is less of a problem for CCS than for investment in low-carbon technologies (column 7). This is because CCS power plants can be located close to where electricity is consumed – requiring less network investment – and because building and operating such plants fit well the current business of incumbent electricity producers. That said, interdependence between investment in CCS and the infrastructure necessary to transport carbon to where it will be stored can easily end in a chicken-and-egg deadlock and, thus, a barrier to investment of primary importance (column 7).

- Finally, policy failures (column 8) – to be discussed in section 3.4 – might needlessly raise the cost of promoting CCS.

3.2.2 Adaptation

As set out in chapter 2, there are many forms of adaptation that do not require any investment – such as changes in planting seasons in agriculture, for instance. Adaptation of this kind is not considered here. Rather, the focus is on adaptation that requires investing with a view to protecting against adverse climate impacts – present or future. As also discussed in chapter 2, adaptation can be grouped along different dimensions. The one followed here distinguishes between private and public adaptation.

Private investment in adaptation

Fear of climate change confronts people with three principle choices: they can self-protect – that is, adapt – purchase insurance against climate-change damages, or do nothing. Of course, they might go for a mix: self-protecting to some extent, seeking partial insurance, and coping with uninsured damages when they occur. For an optimal mix, the proverbial last euro creates the same benefit regardless of whether it is spent on adaptation or insurance, or saved with a view to coping with damages retroactively. A starting point for the discourse that follows is the view that people seek an optimal mix. The question, then, is whether market failures, behavioural failures, other barriers to investment and policy failures prevent such an outcome or suggest that people's decisions produce results that are not in the best interest of society at large. Given the distinction made here between private and public adaptation, the public-good market failure is assumed to

	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers	Policy failure
Private adaptation	*N*	*S*	*N*	*N*	*S*	*S*	*N*	*

be of no relevance, but as it will become clear, things are not black and white. For ease of reference, below is the relevant extract from Table 1.

Externalities

Except for technology externalities, the externalities explicitly listed in Table 1 and other externalities do not radically dent investment in privately rational adaptation and are thus considered of no or little importance. A few qualifications are of interest, however. One cannot rule out external effects resulting from the absence of private adaptation. To illustrate, consider a residential area where some homeowners make their homes more storm resilient while others don't. Suppose a storm hits this area and assume that damages to vulnerable homes affect others as well – picture hurling debris, for instance. Whether this gives rise to a negative externality depends on whether or not homeowners, who have not invested in making their property more storm resilient, are liable for the damage inflicted on others. If they are, there is no externality. But it is also true that a homeowner who has adapted his house cannot exclude others from the benefits of adaptation, and the benefits that accrue to him are not reduced because others also benefit. Thus, even private adaptation could have public-good characteristics.

Staying with the example of storm protection, another qualification must be made. After a storm has hit, those who have suffered losses might seek government compensation – pointing to their personal fate – and if help is granted, damages are socialised. To be clear, this is no market-failure externality. Rather, it reflects one of many possible policy failures that could impede investment in private adaptation.

One may also wonder whether adaptation possibly contributes to climate change. Investment in air conditioning in response to rising temperatures and higher frequency of heat waves is a case in point. Another example is investment in desalination plants in response to increasing freshwater scarcity. Both adaptation investments increase carbon emissions if the additional electricity used comes from fossil fuel-fired power plants. While this is true, the additional emissions are not due to adaptation *per se*, but the use of fossil fuel-fired power plants, which creates the negative externality discussed above in the context of low-carbon investment. To put it differently: if zero-carbon power plants met the extra demand for electricity, there is no climate-change externality.

A last qualification concerns technology externalities. Just as efforts to cut carbon emissions induce technological progress, so can adaptation – private or public – spur demand for innovative products and processes. It follows that the development and commercialisation of innovative adaptation technologies might also be held back by technology externalities. But as in the case of mitigation, there is no reason to presume that technology externalities affect adaptation investment more than any other investment.

Information problems and uncertainty

Imperfect information on climate-change impacts might make people underinvest in adaptation. Information on climate-change impacts clearly has public-good characteristics and there is, thus, a case for governments to provide it.

Asymmetric information between lenders and those who plan to invest in adaptation might limit adaptation finance. Although lack of finance because of asymmetric information possibly affects investment in general, it could be especially relevant for private adaptation investment. This is because investing in adaptation does not generate a stream of revenue that would help to convince lenders. Rather, adaptation benefits come in the form of avoided damages, which are similar to the avoided fuel cost in the case of investment in energy savings.

Similar to investment in energy savings, asymmetric information might hinder investment in adaptation in the housing sector. This is because owners of property do not invest in adaptation if they cannot recoup investment cost (when they sell or let) – which they cannot if potential buyers or tenants fail to properly assess how climate resilient the property is.

All in all, information problems might hinder investment in adaptation, but they do not seem to be as important as in the case of energy savings. Rather, it is sensible to consider them as on a par with those affecting low-carbon investment and carbon sequestration.

An issue that merits a few thoughts is uncertainty – *i.e.* imperfect information about the future. While there is a consensus that the climate is changing, expected impacts are fairly uncertain and they would remain uncertain even if people gathered and processed all the information available. In these circumstances, it might be perfectly rational to delay investment until some of the uncertainty has cleared. Delay might be particularly justified in the case of anticipatory adaptation – *i.e.* investment aimed at protecting against anticipated climate change as opposed to climate change already experienced. Interestingly, delay might be worthwhile even if a discounted cashflow analysis showed that the net present value of an adaptation investment carried out today is positive. The crux is that the investment could be even more profitable if carried out later. Virtually all investment opportunities include the option of delaying the investment. Given the option to delay and sequence investment, a seemingly inefficient lack of investment in adaptation could be a perfectly rational response – from the perspective of households, firms and society – to imperfect information and uncertain climate-change impacts.[43]

Behavioural failures

Behavioural failures affect private investment in adaptation in similar ways as investment in energy savings, notably investment of households. Prospect theory suggests a seemingly anomalous preference for the *status quo* and, therefore, a lack of adaptation even if it is rational, and the same applies to bounded rationality. But as in the case of energy savings, while it is easy to contemplate behavioural failures that could adversely affect investment, it is much harder to gauge their size and the policy response to correct them. More fundamentally, correcting behavioural failures implies the value judgment that policy should make people act how they are assumed to act in traditional economics. Overall, at best, behavioural failures might be considered a secondary obstacle to private investment in adaptation.

Miscellaneous market failures and barriers to investment

Although the analysis developed here explicitly puts aside distributional concerns, it is clear that one obstacle to private investment in adaptation could be lack of means – *i.e.* when poor households simply cannot afford to invest in self-protection.

Policy failures

The picture emerging so far is one with few serious obstacles to private adaptation investment, though with scope for governments to help lessen informational problems. However, as noted at the outset, adaptation is only one possible response to climate change; others are insuring against and 'enduring' climate events. Two issues arise in this context. First, governments must not distort people's incentives to choose a proper balance between adapting, insuring and enduring – and as mentioned above, when people count on government help after climate events, they might adapt and insure less than they should. Second, a proper balance requires functioning insurance markets. There are two obstacles here. First, insurance is also prone to informational problems, possibly resulting in an undersupply of insurance against climate risks. Second, while there might be scope for government intervention to make insurance markets work better, intervention could easily go astray and hinder the supply of insurance rather than promoting it. These issues will be further explored in section 3.4.

Public investment in adaptation

Discussions on how events such as market failures could affect public investment in adaptation is a little anomalous. This is because public adaptation investment – as one form of government intervention – is meant to overcome these failures. Specifically, public adaptation is a public good since it delivers a good from which nobody can be excluded and which generates an advantage to individuals that does not diminish with the number of individuals benefiting from it. A classic example is a dyke that indiscriminately protects people living behind it. Given that public adaptation is a response to market failures, behavioural failures and so on, there is indeed no great need to explore how they impact on public adaptation. That said, it is worth noting a few points.

	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers	Policy failure
Public adaptation	*N*	*S*	*N*	*N*	*S*	*S*	*N*	*

Externalities and public goods

Public adaptation in one province or community could have positive or negative impacts that spill over onto others. A case in point is river-flood protection: the investment of one community could protect neighbouring communities located in floodplains, but it could also put other, notably downstream communities at greater risk. The first situation shows that investment in adaptation of one community might be a public good not only from the perspective of its citizens, but also from the perspective of other communities. Both situations picture an externality (the first a positive and the second a negative one) imposed by one community on others, suggesting the need for coordinating the responses of different communities or delegating decisions on public adaptation to that level of government that would internalise these externalities. Without coordination or proper delegation, investment is bound to be sub-optimally low when externalities are positive and too high when they are negative.

Information problems, behavioural failures and uncertainty
While one cannot rule out that informational and behavioural problems hinder public adaptation, they can be considered of secondary importance and perhaps less relevant than in the case of private adaptation investment.

As pointed out in the context of anticipatory private adaptation, it is fairly well known that climate change will happen, but it is less well known how and how fast it will play out. In these circumstances, it might be welfare enhancing to delay and sequence investment in public adaptation. To put it differently: seemingly too little public investment in adaptation might be an efficient course of action in light of climate-change uncertainty – a theme to be further developed in section 3.3.

Policy failures
Contemplating the right amount and timing of public adaptation investment presumes that public decision makers are rational and farsighted to begin with. If they are not, too little investment might come too late. Besides obvious policy failures of this nature, more subtle ones will be explored in section 3.4.

3.2.3 Summing up

Looking at the full picture as presented in Table 1, we see that a pattern is emerging. For adaptation, it is difficult to identify underinvestment reasons of primary importance – except that some adaptation has the characteristic of a public good, which the very presence of the category public adaptation in Table 1 shows. However, as will transpire from section 3.4, policy failures can be a primary reason for inefficient adaptation. As for mitigation, underinvestment in low-carbon technologies and carbon sequestration is caused by the same primary reasons: the climate-change externality and the global public-good nature of cutting carbon emissions. By contrast, informational and behavioural problems are the main reasons for underinvestment in energy savings.

3.3 Tackling underinvestment – a generic view

The previous section developed a taxonomy that maps underinvestment reasons to different types of climate investment – summarised in Table 1. This section presents a taxonomy that maps underinvestment reasons to possible solutions to underinvestment. While the view taken is a generic one, the examples used for illustrating solutions fit the climate-change context.

Following Weimer and Vining (2011), possible solutions can be grouped under five headings: markets, incentives, rules, insurance and non-market supply. As Table 2 indicates, each type of solution may come in different varieties. A heavily shaded area in Table 2 indicates a solution of primary importance for the problem at hand (*P*); a lightly shaded area signals a solution of secondary importance (*S*); and no shading (*N*) means that the solution is largely irrelevant. In contrast to the distinction in section 3.2 between primary and secondary reasons for underinvestment, the distinction between solutions of primary and secondary importance is not judgmental. Rather, reflecting the general principal that policies should address problems as directly as possible, the dividing line is that primary solutions (*P*) aim to remove the cause of the problem while secondary solutions (*S*) merely try to correct its consequences.

While it should be irrelevant whether or not economically efficient solutions require public funds, the fiscal dimension cannot be ignored when public finances are under exceptional pressure. Against this background, the analysis that follows highlights fiscal implications as and when of importance.

3.3.1 Markets

At first glance, it seems surprising to mention markets as a solution to market failures and the like. It is not a contradiction, however, given that markets might fail because they lack ingredients crucial for efficient outcomes or they do not exist at all. Important ingredients are well-defined and enforced property rights. They are missing, for instance, for common property

Table 2: Mapping investment barriers to solutions to remove them

	Market failures, behavioural failures & other investment barriers						
Problems	Externalities			Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers
	Env't (–)	Tech (+)	SoS (–)				
Solutions							
Markets							
Establishing property rights	*P*	*P*	*N*	*N*	*N*	*N*	*N*
Creating new marketable goods	*P*	*N*	*P*	*N*	*S*	*S*	*N*
Incentives							
Taxes	*P*	*N*	*P*	*N*	*N*	*N*	*N*
Subsidies	*S*	*P*	*S*	*S*	*S*	*S*	*S*
Rules							
Frameworks	*P*	*P*	*P*	*P*	*P*	*P*	*P**
Command & control	*S*	*N*	*S*	*N*	*P*	*P*	*N*
Nudge	*N*	*N*	*N*	*N*	*P*	*P*	*N*
Enhanced appraisal	*N*	*N*	*N*	*N*	*P*	*N*	*P**
Insurance	*N*	*N*	*N*	*N*	*P*	*P*	*P***
Non-market supply	*N*	*N*	*S*	*P*	*P*	*N*	*P****

P = Primary solution.
S = Secondary solution.
N = Not a solution or a mapping not analysed.
* = Primary solution when enhanced appraisal helps to properly account for climate-change policy uncertainty.
** = Primary solution when people bank on government bailout in a climate-risk event.
*** = Primary solution when non-market supply is best response to natural-monopoly market failure.

Env't stands for environmental externalities, notably the climate-change externality of greenhouse-gas emissions. *Tech* stands for technology externalities, *i.e.* knowledge spillovers. *SoS* stands for security-of-supply externality. The + sign and the – sign in columns (1) to (3) indicate, respectively, positive and negative externalities.

resources, which results in an overuse and possible depletion of them. From a climate-change perspective, a big failure is lack of well-defined ownership of tropical forests, making them free for all and, thus, accelerating deforestation. To slow this process and reduce emissions from deforestation, establishing and enforcing property rights is of primary importance. Ownership rights alone will not do the trick, however. Forest owners must also have the rights to any benefits from preserving forests and they need to be appropriately rewarded for preserving them (see below). Missing or ill-defined property rights could also hinder technological progress, a problem that the granting of patents, which establishes property rights on knowledge, tries to address. It is fair to consider clear property rights of primary importance for tackling technology externalities – in general and when such externalities impede climate investment.

Closely related to establishing property rights is the creation of markets where none exist.[44] The creation of tradable permits is the most common form of creating markets. Prominent in the context of climate change is the creation of tradable carbon emission permits – the most noteworthy example so far being the European Union Emissions Trading Scheme (EU ETS). Such 'cap-and-trade' schemes cap emissions, establish a permit price and channel scarce permits to emitters who value them most. The cap limits the external damage that emitters impose on others and the permit price makes them pay for the damage. Like carbon taxes, which will be discussed under the heading incentives, cap-and-trade for carbon emissions constitutes a primary solution to the climate-change externality.

One could think of tradable certificates for a variety of other goods. Most famously, there could be 'green' certificates verifying the production of renewable energy. The background to this would be a government rule that obliges energy producers to produce a certain amount of renewable energy or, alternatively, buy green certificates from producers that have done so. 'White' certificates that verify energy savings are another possibility. Under a white certificate scheme energy suppliers are obliged to meet energy saving targets or buy white certificates from other suppliers. Finally, one could imagine security-of-supply certificates that prove investment in storage of oil and gas. Under a security-of-supply certificate scheme oil and gas importers would be required to store minimum amounts of oil and gas or buy certificates from other firms.

In sum, establishing property rights and creating markets could help internalise externalities, namely the climate-change externality, the positive technology externality and the negative security-of-supply externality. Section 3.4 will return to the role of EU ETS and green and white certificate schemes in mitigating greenhouse-gas emissions.

3.3.2 Incentives

There are two broad types of incentives: taxes and subsidies (see the extract from Table 2 below). Taxes aim at reducing the use of goods and services to a level that is optimal from a society's perspective. They achieve this by making prices of goods and services reflect their true economic cost – *i.e.* the sum of private and external costs. The most prominent example in the climate-change context is a tax on carbon emissions, with the tax rate ideally equalling the marginal external damage they cause. Levying such a carbon tax would make the use of high-carbon energy less attractive and thus reduce its use and the emissions associated with it. Obviously, like cap-and-trade, a carbon tax establishes a carbon price. The key difference between the two is that cap-and-trade fixes emissions and lets the market determine the carbon price whereas a tax fixes the carbon price and lets the market determine the amount of emissions.

Problems	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers
Solutions							
Incentives							
Taxes	*P*	*N*	*P*	*N*	*N*	*N*	*N*
Subsidies	*S*	*P*	*S*	*S*	*S*	*S*	*S*

One could also picture a tax to internalise the security-of-supply externality – should it be relevant. The tax would need to be set so that each consumer pays for the rise in vulnerability of all consumers as a result of a growing dependency on foreign energy suppliers with a lot of market power.

Subsidies are the mirror image of taxes. They aim to increase the use of goods and services that markets alone would underprovide. They are a primary solution when used to internalise positive externalities – for instance, when they are granted for basic research and development with a view to raising private returns to R&D so that private returns equal social ones. They could be handed out through various mechanisms, including straight budgetary support, tax credits, cheap loans and preferential prices. Subsidies are a secondary solution for addressing information problems and behavioural failures: while they promote goods and services that are underused because of these obstacles, they do not remove them. Likewise, subsidies could help increase the supply of goods with public-good characteristics, but they would not make such goods excludable and rivalrous. Finally, subsidies could incentivise socially optimal network investment – included under miscellaneous failures and barriers in the table above.

Subsidies could also be handed out for goods that compete with goods that cause external damages.[45] Subsidies in favour of renewable energy are typical. Renewable energy competes with high-carbon energy, and for a given demand for energy, sufficiently subsidising the former pushes out the latter. This is also the case when subsidies take the form of preferential prices (*e.g.* feed-in-tariffs) paid for by energy consumers rather than tax payers. From a climate-change perspective, subsidising renewables is a poor substitute for pricing carbon for a number of reasons. To correctly set the subsidy, one would need to know the carbon content of the energy (*i.e.* coal, oil or natural gas) replaced at the margin, which is impossible as the type of energy replaced at the margin varies over time. What is more, climate-change motivated subsidies in favour of renewables puts competing mitigation technologies at a disadvantage, thereby raising the help they might need – CCS power plants come to mind at once and new nuclear plants might not be far behind. To conclude, subsidising renewables is not a primary solution for reducing greenhouse-gas emissions. In fact, if subsidies are in favour of an activity governed by cap-and-trade – such as electricity generation – there is harmful interaction between policy instruments, a problem further explored in section 3.4.

All in all, taxes and subsidies are primary tools when directly addressing externalities. Even if not directly correcting information problems and behavioural failures, taxes and subsidies can help lessen their impact – for instance, subsidies for investment in energy savings. Table 2 therefore lists incentives as secondary solutions for these problems.

3.3.3 Rules

Government intervention in the form of rules comes in three ways (see the extract from Table 2 below). One is almost too obvious to mention. It comprises the setting and enforcement of frameworks without which there can be no functioning market economy. This type of intervention is arguably of primary importance for avoiding underinvestment in climate-change mitigation and adaptation. Examples include civil and criminal laws, enforcement of property rights and contracts, and anti-trust policy. As mentioned above, dominant incumbents in the electricity sector might discourage low-carbon investment by new entrants, making the supply of low-carbon energy smaller than it would be in competitive markets even if a carbon price encourages investment in low-carbon energy. If anti-competitive behaviour is a serious obstacle to climate action, competition policy must play its role.

Problems	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers
Solutions							
Rules							
Frameworks	*P*	*P*	*P*	*P*	*P*	*P*	*P**
Command & control	*S*	*N*	*S*	*N*	*P*	*P*	*N*
Nudge	*N*	*N*	*N*	*N*	*P*	*P*	*N*
Enhanced appraisal	*N*	*N*	*N*	*N*	*P*	*N*	*P**

Rules of a less innocent and often less benevolent variety fly under the label 'command-and-control'. The salient feature of command-and-control is that it prescribes individual choices. This sets it apart from creating markets and setting incentives. While creating markets fixes the outcome that individual decisions have to observe in aggregate, it nonetheless leaves individuals free to choose. The difference between command-and-control and setting incentives is even more pronounced since incentives do not even prescribe an aggregate outcome, but only try to steer individual choices. The differences are easy enough to illustrate for carbon-emitting power plants: command-and-control would order each of them not to emit more than a certain amount of carbon; a cap-and-trade scheme would limit aggregate emissions, leaving it to the market to determine both the price of emission permits and the emissions of each power plant; and a carbon tax would set the price of emissions and allow each power plant to emit as much as it wants at that price, with aggregate emissions being an *a priori* unknown outcome of this process.

Given the choice between command-and-control, markets and incentives, it is pertinent to ask which is best. While there is no answer that fits all circumstances, economists broadly agree that markets and incentives usually deliver more efficient outcomes than command-and-control – and this also applies to limiting carbon emissions (Jaccard, 2005; Rivers and Jaccard, 2006). There is no consensus, however, whether cap-and-trade is better than a carbon tax. Box 1 sketches the pros and cons of each. There is a tremendously important insight that the debate about carbon tax vs. cap-and-trade must not obscure: central to both instruments is the pricing of carbon emissions. To quote Nordhaus (2008, p.22), one of the leading climate-change economists: "*To a first approximation, raising the price of carbon is a necessary and sufficient step for tackling global warming*". A corollary is that carbon taxes and cap-and-trade can rationally coexist (for example, cap-and-trade in one country and carbon taxes in another, or cap-and-trade for some activities and carbon taxes for others) provided they establish similar carbon prices. That said, when there is carbon taxation and cap-and-trade, good policy design is needed to avoid a costly and counterproductive interaction of both instruments – a challenge to be further examined in section 3.4.

Box 1: Carbon tax and cap-and-trade – two instruments that address the climate change externality head on[46]

With perfect information and certainty about key decision-making variables, cap-and-trade and carbon taxes would lead to the same cut in carbon emissions. What is more, both instruments would be economically efficient. Without perfect information and certainty, however, this is not so, and a trade-off between environmental effectiveness and economic efficiency arises.

More specifically, taxing carbon promises greater economic efficiency than cap-and-trade. The reason is – loosely put – as follows: when true marginal mitigation costs differ from expected costs, taxing carbon leads to a relatively small deviation from both the optimal cut in emissions and the optimal price that emitters should pay; by contrast, cap-and-trade results in a relatively large deviation – implying that emissions are capped at the given level regardless of cost.

However, an advantage of cap-and-trade seems to be that even if true mitigation costs differ from what was expected, cap-and-trade is environmentally effective in that it ensures emissions in line with the cap. By contrast, taxing carbon in a world with higher-than-expected mitigation costs results in emissions in excess of what could have been achieved by cap-and-trade.

In short, the choice between carbon taxes and cap-and-trade boils down to a choice between economic efficiency and environmental effectiveness. If economic efficiency is of overriding concern, carbon taxes come to the fore. By contrast, if environmental effectiveness is the main objective, cap-and-trade wins.

Alas, things are not that simple. The apparent effectiveness of cap-and-trade in meeting emission targets might be illusory. This is because policymakers might raise the cap if carbon prices (and thus the cost of climate-change action) turn out unbearably high.

While the carbon tax vs. cap-and-trade debate continues (with prominent climate-change economists favouring taxes), the current thrust continues to be on extending the coverage of cap-and-trade and on tightening emissions limits. In part this is because policies have been steaming along the cap-and-trade track since Kyoto and the creation of EU ETS.

Stating that markets and incentives usually deliver more efficient outcomes than command-and-control allows exceptions and, indeed, informational problems and behavioural failures might be better dealt with through command-and-control. Consider, for instance, investment in energy savings blocked by asymmetric information. In these circumstances, command-and-control could prescribe energy passes for houses and apartments. Energy passes would certify energetic characteristics of houses and apartments, notably their heat loss, actual energy consumption over number of years (for existing buildings) and energy consumption under standard conditions. Likewise, household appliances can be required to carry energy labels that give accurate information about their energy consumption. Both energy passes and energy labelling have been introduced in the EU and other advanced economies.

Related to energy labels, a case can be made for setting product standards (including building regulations), even if that effectively narrows choice. In fact, behavioural economics suggests that narrowing the range of energy investments people can choose from might improve the chance that investments are made in the first place. The underlying logic is that because of cognitive limitations, people tend to procrastinate and, perhaps, do not choose at all if there is too much to choose from (Aldred, 2009).

Moving on from asymmetric information to simply poor information, more timely and easier-to-process information could trigger energy savings. A case in point is information on household energy consumption, which households typically receive once a year (though they pay more frequently on the basis of expected consumption). Annual energy records normally do not show the pattern of energy consumption over time and how it relates to users' behaviour, which they might alter if they knew how it affects their energy bill. Compelling energy utilities to provide timely, informative and intelligible energy records could help encourage energy savings, including those requiring upfront investment. Pushing for improved information is arguably only one aspect of broader demand-side management – eventually based on smart metering of energy consumption – but it is a measure that does not need to wait until more sophisticated means of demand-side management can be rolled out.

The next type of rule featuring in the abridged version of Table 2 may be called 'nudge' or 'libertarian paternalism' – terms coined by Thaler and Sunstein (2008). It implies regulating the circumstances of choice with a view to nudging people towards taking socially desirable decisions they would not otherwise take. Take contributions to defined pension schemes, which are often considered too low. Instead of leaving it to people to opt-in to such schemes, nudge would make participation the default, but give people the choice to opt out. Ignoring transaction cost, self-interest and rationality suggest that participation and pension savings will be the same under both options – empirical evidence, however, shows that participation is higher when people are nudged into pension schemes.

Returning to the issue of information on energy consumption, the role of nudge in climate-change mitigation and adaptation is easy to illustrate. Thaler and Sunstein (2008) recount the experience of an electric utility company that tried to make its customers conserve energy by notifying them in real time, via email and text messages, of their energy consumption. But this did not dent people's energy use. The utility then gave customers an 'ambient orb' – a little ball growing red when their energy use was high and green when it was low. Within weeks, energy use during peak time was reported to have dropped by 40 percent. The orb thus nudged customers into saving energy where the same information provided via email and text messages failed to change behaviour.

Oullier and Sauneron (2011) discuss other cases where nudge has shown its potential to make people's environmental behaviour contribute better to maximising society's welfare, and the failures nudge can address go beyond information problems. As explained above, people might anchor their behaviour – in the case of energy use, for instance, to the average consumption of a peer group. To illustrate, an experiment found that people did not reduce their use of energy when merely being made aware of their consumption. But users with a higher-than-average energy use visibly cut consumption when their energy bill – embellished with a Smiley – made them aware that their consumption exceeded the norm.

For the examples mentioned, the issue was primarily one of changing behaviour without boosting investment. Kotchen (2010) provides evidence for people being nudged into demanding green electricity. There might also be scope for nudging firms into green competition and cities into competition for becoming the most climate friendly and climate-change resilient city (Kahn, 2010). All in all, nudge might offer a largely untapped, low-cost potential to help overcome informational and behavioural obstacles to economically efficient outcomes and foster investment in climate-change mitigation and adaptation.

Turning to the last rule in Table 2, an admission is due upfront: unlike all other solutions, enhanced appraisal is not a public-policy tool. Rather, it is a call for applying – as and when needed – an investment appraisal technique that goes beyond standard discounted cashflow analysis. Enhanced appraisal is useful primarily to overcome information problems and when uncertainty is a major barrier to investment. The main result of enhanced appraisal is an investment-decision rule that adds an element to the net present value (NPV) criterion following from standard analysis – one may call this rule NPV+. The annex at the end of this chapter sketches the essence of NPV+, when it makes sense (and, equally important, when NPV is informative enough), and how to determine the 'plus' in NPV+. The key point is that NPV+ reveals information on investment that standard discounted cashflow analysis fails to expose, and this is mainly because NPV+ explicitly values the option of taking investment decisions in light of how uncertainty resolves. Zooming in on climate-change mitigation and adaptation investment, four informational aspects stand out.

First, reflecting its treatment of decision making under uncertainty, NPV+ provides information on and allows for a proper estimation of the benefit of building into today's investment scope for future action and of using that scope as and when useful. To illustrate, the benefits from investment in coastal flood defences depend on how much the sea level will rise – a climate-change impact that is uncertain. Against this background, it might make sense to invest in moderate rather than massive flood defences today and to choose a design – even a costly one – that makes it possible to upgrade flood defences in the future if necessary in light of how the uncertainty about rising sea levels resolves itself. The important point is that NPV+ might show that investing moderately and flexibly is better than investing massively, although a standard discounted cashflow analysis suggests the opposite.

Second, NPV+ provides information on the proper timing of investment. As mentioned in the previous section, virtually all investment can be delayed since investing is rarely a question of now or never. NPV+ makes explicit the value of waiting. To build on the previous illustration, consider the case of investing moderately and flexibly. Since NPV+ explicitly accounts for how uncertainty about rising sea levels might resolve itself in the future, it could suggest that even investing moderately and flexibly makes more sense tomorrow than today.

NPV+ allows a better evaluation, too, of growth opportunities created by an investment. Consider innovative investment in low-carbon energy technologies and sequestration, for instance. Investing in these technologies might enable profitable follow-up investments. For example, with the experience gained in successfully deploying offshore wind farms in one location, investors have the option to move into other locations. And then, the experience gained with the initial investment might point to profit-enhancing modification to offshore wind farms (including scaling up the capacity of wind turbines) and their operation – an option that could not be exploited without the initial investment. NPV+ is more suitable than standard discounted cashflow analysis for appraising investments that create such growth opportunities. Indeed, it puts a monetary value to growth opportunities, thereby possibly mobilising finance that would not be forthcoming otherwise, notably when NPV+ identifies profitable investments that standard analysis finds unprofitable.

Finally, as Blyth *et al.* (2007) and Yang *et al.* (2008) show, NPV+ sheds new light on the impact of climate-change policy uncertainty on mitigation investment and, by extension, the need to minimise policy uncertainty. They consider carbon pricing as the tool for encouraging investment and examine how uncertainty about policies that govern carbon prices (*i.e.* resetting the carbon tax or the cap under cap-and-trade) affect investment. Three findings are worth highlighting. First, the carbon price needed to encourage investment is substantially higher with than without policy uncertainty – in other words, for given carbon price expectations, uncertainty about policy-driven carbon price shocks curb investment as firms choose to wait until uncertainty has resolved. Second, the detrimental effect of policy uncertainty is higher nearer the time of an anticipated change in policy. Third, policy uncertainty affects the choice of technology and might reduce low-carbon investment in favour of investment in high-carbon technologies that only build in a CCS retrofit option rather than including CCS in the first place. In sum, to make climate investment happen, climate-change policy must be clear, predictable and credible.

To conclude on rules: from an economic efficiency viewpoint, they are poor solutions when underinvestment in climate-change mitigation and adaptation is due to externalities. However, they can play a primary role when informational and behavioural problems cause underinvestment.

3.3.4 Insurance

The purpose of insurance is to shield the insured against unfortunate outcomes. Including insurance in the list of solutions to market failures and the like implies two things: insurance markets, on their own, underprovide insurance because of these failures and government intervention can raise the supply of or demand for insurance. More specifically, making insurance mandatory or subsidising it could make insurance approach its optimal level. But what is the link between insurance and climate investment?

In the context of climate change, bringing about the right level of insurance is of primary importance for overcoming underinvestment in adaptation, in particular its private component. To recall from the previous section, an economically efficient response to expected climate-change impacts is characterised by a proper balance between self-protection, insurance and endurance. Because of information problems, bounded rationality, uncertainty and misperception of risk and policy failures, choices are likely to be biased against self-protection and insurance. In these circumstances, government intervention in the provision of insurance might help. More on this follows in section 3.4.

Problems	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers
Solutions							
Insurance	***N***	***N***	***N***	***N***	***P***	***P***	***P*****

3.3.5 Non-market supply

The common trait of the solutions presented so far is that they work through markets – by creating and nourishing them, changing and complementing the signals they give, and by regulating or even instructing them on what to deliver. As its name indicates, the last type of solution does not rely on markets and it can be seen as more intrusive than the other solutions. Non-market supply is a primary solution to address the public-goods market failure and natural-monopoly market failure – the latter is included under miscellaneous failures in the table below.

Problems	Env't (–)	Tech (+)	SoS (–)	Public goods	Information problems	Behavioural failures	Miscellaneous market failures & other barriers
Solutions							
Non-market supply	***N***	***N***	***S***	***P***	***P***	***N***	***P****

A natural monopoly has two salient features: first, demand for its output is typically not big enough to allow room for more than one supplier and, thus, the lone supplier could exploit its market power and overcharge for its output; second, even if it does not, the price it needs to charge to fully cover costs would prevent demand from reaching its welfare maximising level. In the context of climate change, the most relevant natural monopolies are the transmission of electricity (of which more is required in a low-carbon energy system) and the transport of carbon dioxide, which nestles between carbon capture and carbon storage.

A solution to the first part of the problem is to regulate the natural-monopoly supplier so that it does not overcharge. A solution to the second part is to subsidise the natural-monopoly supplier so that it reduces the price to the level that ensures the welfare-maximising level of demand (this solution was mentioned above in the context of subsidies). A non-market alternative to solving both parts of the problem is supply by a government department or a government-sponsored independent agency. Current practice in nearly all industrial countries is to regulate natural monopolies – privately or publicly owned – without necessarily subsidising them with a view to stimulating the welfare maximising level of demand.

Turning to public goods, the most obvious solution is for governments to supply them – either directly through government departments or agencies or indirectly by contracting out their supply to profit-making firms. In the climate-change context, two public goods are of particular importance. One is information with public-good characteristics, including information on energy-saving technologies and their performance, climate change and its impacts and on private adaptation options.

Another is, of course, infrastructure dedicated to protecting against climate-change impacts – *i.e.* public adaptation investment. There are many challenges in making public adaptation investment efficient. As will be examined in section 3.4, a key point is to levy the taxes needed to finance the investment on firms and households that benefit from it.

Finally, the table shows non-market supply as a secondary solution to the security-of-supply externality. This captures government strategic oil and gas reserves. While not directly addressing the underlying market failure – should there be one – strategic reserves would lessen its consequences.

3.3.6 Summing up and conclusions

Four key insights emerge from the taxonomy summarised in Table 2. First, primary solutions to underinvestment caused by externalities cluster in the market/incentives corner of the table. By contrast, primary solutions to underinvestment caused by informational and behavioural problems concentrate in the rules/insurance/non-market supply area of the table. Second, solutions requiring fiscal resources are subsidies and non-market supply. Third, except for the technology externality, primary solutions to externalities do not require fiscal resources whereas secondary solutions do. In this context, it is useful to bear in mind Europe's ambition to increase its spending (public and private) on research and development to 3 percent of GDP. Given this target, stepping-up fiscal support for climate-related R&D does not necessarily imply a greater budgetary burden, but it will leave less space for supporting R&D in other fields. Fourth, except for the non-market supply – that is, public supply – of information, all primary solutions for informational and behavioural problems do not require fiscal resource whereas secondary solutions do. By and large, then, there seems to be a virtuous coincidence between solutions of primary importance and those that are fiscally neutral – if not benign as in the case of carbon pricing – and *vice versa*: solutions of secondary importance tend to be fiscally demanding.

3.4 Tackling underinvestment – a close up of climate investment

Section 3.2 developed a taxonomy that maps underinvestment reasons to different types of climate investment – summarised in Table 1. Section 3.3 developed a taxonomy that maps underinvestment reasons to possible solutions to underinvestment – summarised in Table 2. Combining both taxonomies creates a conceptual framework for analysing every conceivable climate investment to determine why there might be too little of it and how to boost it. This section applies this framework to investment in low-carbon technologies and CCS, residential energy savings, and private and public adaptation. The presentation complements section 3.3, which – though generic – draws on the climate-change debate to work out primary and secondary solutions.

3.4.1 Investment in low-carbon technologies and CCS

As investment in low-carbon technologies and CCS is hindered by very similar failures and barriers, requiring similar solutions, the two types of mitigation investment are treated in one sweep – with the label low-carbon investment referring to both. In Table 3, the red and orange columns signal, respectively, primary and secondary reasons for too little low-carbon investment – as identified in section 3.2 and summarised in Table 1. For ease of presentation, policy failures (shown in the last column of Table 1) are subsumed under 'miscellaneous' in Table 3. To avoid clutter, Table 3 does not show any entries where the solution at hand is not relevant (the *N's* in Table 2). For the same reason, the column 'behavioural failure' and all primary and secondary solutions that do not apply to low-carbon investment are discoloured (*i.e.* they are shown in 'white'). The remaining entries make up the framework for analysing obstacles to low-carbon investment and how to overcome them. To highlight primary solutions, table entries are bordered: red for primary reasons and orange for secondary ones. The main purpose of the following analysis is to connect the *Ps*, that is, to find primary solutions for primary obstacles.

Drawing on the survey of generic solutions, Table 3 shows the creation of new markets (*i.e.* cap-and-trade) and taxes (*i.e.* carbon taxes) as primary solutions to the climate-change externality. In the EU, the most prominent instrument is EU ETS, a cap-and-trade system, but carbon taxes are levied, too, in individual EU countries such as the United Kingdom, Sweden and Denmark. In principle, cap-and-trade governing one set of emissions and carbon taxes levied on another can jointly encourage an efficient switch towards low-carbon investment, provided the two instruments do not establish too different carbon prices. However, cap-and-trade and carbon taxes imposed on the same emissions can be harmful, as an increasing amount of research on the interaction between climate-change policy instruments shows (see, for instance, Sorrel and Sijm, 2005; Abrell and Weigt, 2008; De Jonghe *et al.,* 2009; Fischer and Preonas, 2010; Levinson, 2010; and OECD, 2012).

The critique of Fankhauser *et al.* (2011) is especially compelling. One of their conclusions is that levying a carbon tax on emissions subject to cap-and-trade cannot push emissions below the cap. Another conclusion is that a carbon tax reduces the carbon permit price one-for-one if all countries participating in the cap-and-trade levy the tax. That is, the penalty on carbon emissions (*i.e.* the sum of carbon tax and permit price) remains unchanged and, thus, the incentive to invest in low-carbon technologies is not made bigger by stacking a carbon tax on top of cap-and-trade. If only a subset of countries levies the tax, the permit price falls by less than the tax. While still not pushing emissions below the cap, this makes carbon penalties differ from country to country; in countries that levy the tax, the carbon penalty (which is the tax plus permit price) increases whereas in countries that do not levy the tax, the penalty (the permit price) falls. With a higher penalty in tax-levying countries than in the rest of the cap-and-trade area, relatively costly mitigation options in tax-levying countries replace cheaper options in the other countries – and there is full substitution given constant aggregate emissions. This increases mitigation cost for the cap-and-trade area as a whole. Not in contradiction with their critique, the authors rightly stress that cap-and-trade can be meaningfully combined with carbon taxes if they establish a floor and/or a ceiling for the carbon permit price, implying that when the carbon price reaches the floor or the ceiling, carbon emitters pay the tax in lieu of purchasing permits. Such hybrids between cap-and-trade and carbon taxes are discussed in McKibbin and Wilcoxen (2002), for instance.

As explained when exploring generic solutions, subsidies in favour of low-carbon investment are a secondary solution to the climate-change externality.[47] More important, subsidies in favour of an activity governed by cap-and-trade – such as electricity generation – interact with cap-and-trade in harmful ways, for reasons similar to those behind the interaction between cap-and-trade and carbon taxes. Box 4 in chapter 4 sketches the economics underpinning this conclusion. It is sufficient to note here that such subsidies cannot make carbon emissions smaller than the cap, but they lower the price of carbon permits unless, that is, the cap is sufficiently tightened at the same time. This price decline has at least four adverse consequences. Most

Table 3: Mapping investment barriers to solutions – *Low-carbon investment and CCS*

	Market failures, behavioural failures & other investment barriers						
Problems	Externalities			Public goods	Information problems	Behavioural failures	Miscellaneous: Lack of competition Policy uncertainty Lack of coordination
	Env't (–)	Tech (+)	SoS (–)				
Solutions							
Markets							
Establishing property rights	P	P					
Creating new marketable goods	P		P		S	S	
Incentives							
Taxes	P		P				
Subsidies	S	P	S	S	S	S	S
Rules							
Frameworks	P	P	P	P	P	P	P*
Command & control	S		S		P	P	
Nudge					P	P	
Enhanced appraisal					P		P**
Insurance					P	P	P
Non market supply			S	P	P		P

[red] = Primary failure or barrier
[yellow] = Secondary failure or barrier
P = Primary solution.
S = Secondary solution.
* = Promoting competition is a primary solution if lack of competition hinders low-carbon investment. Adequate regulation is needed to incentivize network investment. Public coordination – if not planning – is a primary solution if low-carbon investment waits for complementary network investment and *vice versa*.
** = Enhanced appraisal helps explain underinvestment due to climate policy uncertainty, suggesting policy certainty and credibility as a primary solution

Env't stands for environmental externalities, notably the climate-change externality of greenhouse-gas emissions. *Tech* stands for technology externalities, *i.e.* knowledge spillovers. *SoS* stands for security-of-supply externality. The + sign and the – sign in columns (1) to (3) indicate, respectively, positive and negative externalities.

obviously, it undermines the very incentive that carbon pricing is meant to give. Second, it encourages the use of the dirtiest of the fossil fuels. Third, it distorts the level playing field for alternative low-carbon technologies unless, that is, all are subsidised in a non-distorting manner. Fourth, it reduces proceeds from auctioning carbon permits and, hence, forgoes revenue that could be used for a variety of worthwhile purposes – including general tax cuts, research and development, helping the poor to cope with a carbon-price induced rise in energy cost and assisting developing countries in their efforts to cut carbon emissions and adapt to a changing climate.[48] For completeness, note that granting preferential prices, such as feed-in tariffs for renewable electricity, is a form of subsidy that lowers carbon prices in the same way as budgetary subsidies.

To be clear, the argument against subsidies in favour of investment that cap-and-trade aims to incentivise only applies to subsidies given with the intention to curb carbon emissions. As Table 3 indicates, subsidies can be a primary solution to technology externalities, like establishing property rights on knowledge (*i.e.* granting patents). The challenge is to correctly target the subsidy and to specify its size. While exploring this challenge would go beyond the scope of this chapter, it is worth making two observations. One concerns the target of subsidies, that is, the question of what precisely should be subsidised. Recall that one argument in favour of supporting known, innovative low-carbon technologies is that they do not penetrate the market as fast as they should from society's viewpoint because of learning and experience spillovers. A well-targeted subsidy would reward firms for creating these spillovers. But for this one needs to know how learning and experience spills over from one firm to another. One channel is when learned and experienced workers of an innovating firm quit that firm to join another firm. There is, then, a case for subsidising on-the-job training of workers engaged in the learning and experience process. Alternatively, a case can be made for subsidising demonstration plants on condition that the learning and experience gained in this endeavour is made available to other firms in the industry. By contrast, a long-term output subsidy does not seem to be first-best unless it is well targeted to the early movers in trying out new technologies. This brief detour serves to show that it is relatively easy to contemplate subsidies as a means to internalise technology externalities, but it is much harder to ascertain what exactly should be subsidised.

The second observation concerns the right size of the subsidy, which is perhaps even harder to determine than what should be subsidised. But a qualitative judgment is possible. Before cap-and-trade, one could argue that subsidies were meant to achieve two things: rewarding investments for reducing carbon emissions and rewarding investments for creating positive technology externalities. After cap-and-trade, the first *raison d`être* no longer holds as the cap ensures targeted emission cuts. As a result, one would expect the subsidy for low-carbon investment to be smaller, perhaps substantially, after introducing cap-and-trade.[49] Although subsidies motivated by technology externalities reduce carbon prices, too, this is economically efficient in contrast to a situation where unjustifiably high subsidies survive in a cap-and-trade world.

To finish off the discussion of policies addressing lack of low-carbon investment due to climate-change and technology externalities, it is worth commenting briefly on green certificate schemes, which exist in the United Kingdom, for instance. In contrast to a carbon cap-and-trade, a green certificate scheme does not directly address the climate-change externality, but it works towards achieving a given renewable target at the least cost.[50] Whether this is a sensible target is another matter, however. What is more, similar to the subsidies case, cap-and-trade and green certificate schemes can harmfully interact if the latter covers activities that the former tries to encourage – renewable electricity being a case in point. Drawing on Fankhauser *et al.* (2010) and Fischer and Preoans (2010) and the literature reviewed therein, the following insights emerge. First, emissions cannot be cut below the cap as long as the cap binds and, thus, prices of carbon permits remain positive. Second, like subsidies, green certificate schemes might lower carbon prices, thereby discouraging investment in low-carbon technologies not benefiting from a green certificate scheme and encouraging the use of and investment in the dirtiest fossil fuels. Third, green certificate schemes are liable to raise the cost of reducing carbon emissions. Finally, a strong cap can render the renewable target non-binding (thereby pushing the price of green certificates to zero) and, *vice versa*, ambitious renewable targets can make the emission cap non-binding and the carbon price zero.

Turning briefly to the negative security-of-supply externality possibly caused by oil and gas imports, a primary solution would be a tax on imports that internalises this externality. However, if levied only on imported oil and gas, such a tax could be in conflict with WTO trade rules. Alternatively, one could imagine security-of-supply certificates (*i.e.* the creation of marketable goods) that prove investment in storage of oil and gas. Under a security-of-supply certificate scheme oil and gas importers would be required to store minimum amounts of oil and gas or buy certificates from other importers. Subsidies are problematic for similar reasons as they give rise to a free-rider problem in that subsidies reward importers for investment they would have made in the absence of subsidies. Finally, though discoloured in the table, command-and-control and non-market supply should not go unnoticed as they are behind strategic oil and gas reserves held in a number of countries.[51]

Equally brief, a remark on the global public-good market failure that makes each country – or a cooperating group of countries like the EU – choose less low-carbon investment than it would if there was an effective international agreement on climate-change mitigation: Table 3 indicates 'frameworks' as a primary solution, meaning that an agreement in this area would make each country's mitigation larger than it would be in the absence of such an agreement and, ideally, would limit global emissions to a level where the marginal benefits of carbon emissions just equal their marginal costs. Chapter 2 outlines alternative climate-change architectures that could deliver such an agreement, which is surely the most important prerequisite for getting the planet on the low-carbon trajectory presented in chapter 1.

Moving on to information problems, Table 3 signals enhanced appraisal – called NPV+ here – as a solution to informational problems. To recall from section 3.3, NPV+ has the potential to help value growth opportunities that low-carbon investment might create and, thereby, alleviate finance constraints. It is worth adding here that there is an increasing number of academic papers that apply NPV+ to different types of low-carbon investment (for a survey see Fernandes *et al.,* 2011).[52]

The last column in Table 3 mentions, too, enhanced appraisal as a tool to better understand why and how climate policy uncertainty hinders low-carbon investment. OECD (2008) examines this in great detail. A key message is that potential investors need to be confident that carbon pricing – once introduced and set sufficiently high – will remain in place over the lifetime of their investment. Intuition suggests that carbon-price uncertainty fosters a wait-and-see attitude and, thus, delays investments whose profitability crucially depends on carbon prices. To be clear, uncertainty – including carbon-price uncertainty – is an inevitable feature impacting on investment, but policy uncertainty is an avoidable element of uncertainty.

Finally, the intersection of the 'framework' row and the last column in Table 3 makes reference to two primary solutions. First, it highlights the role of competition policy if anti-competitive behaviour of dominant incumbents discourages low-carbon investment by new entrants, making such investment smaller than it would be in competitive markets, even if low-carbon investment indirectly benefits from carbon pricing. Second, creating a low-carbon economy calls for commensurate network investment, notably for electricity transmission and carbon transport (see, for instance, Helm, 2010; Keay, 2011a; Krey and Clarke, 2011; and von Hirschhausen, 2012). Network investment tends to be hindered by the natural-monopoly market failure, and overcoming it requires state-ownership and planning of networks or, if they are privately owned, regulating them in a way that encourages efficient network investment (Helm 2010). Moreover, regardless of whether networks are privately or publicly owned, there is a need to coordinate network investment with investment in the competitively organised part of the supply chain to overcome the chicken-and-egg dilemma discussed in section 3.2. The need for coordination, if not planning, is bound to increase with an increasing geographical mismatch between where low-carbon energy is produced and where it is consumed.

To conclude, the conceptual framework behind Table 3 brings to the fore three crucial elements of a consistent policy response to underinvestment in low-carbon technologies. First, pricing carbon is of primary importance. A major improvement to current policies would be an extension of carbon pricing to emissions other than those currently captured by EU ETS. Another step would be tighter emission caps and/or higher carbon taxes if current mitigation targets are found to be not ambitious enough. And then, to reduce carbon-price policy uncertainty and foster policy credibility, it might be worth exploring mechanisms that make it costly for governments to backtrack on carbon-price policies. Second, economic efficiency and fiscal constraints suggest an overhaul of support for low-carbon investment as put in place before the start of EU ETS and as introduced thereafter. Support in favour of emission reductions covered by cap-and-trade no longer lowers emissions, but it employs resources that could be put to better use – for climate action and other laudable causes. Needless to say: there continues to be an argument for well-targeted and measured support in response to technology externalities created by low-carbon investment. But as OECD (2012) argues, adequate carbon pricing provides much broader incentives for innovation than technology adoption subsidies. The economic case for rationalising the policy landscape as inherited from the days before EU ETS becomes stronger as and when more emissions are brought under EU ETS. Third, policy needs to remove barriers to market entry, properly incentivise network investment and help coordinate network investment and low-carbon investment.

3.4.2 Investment in residential energy savings

The residential housing sector is a good way to illustrate how the conceptual framework espoused here can guide energy-saving policies. The sector is estimated to account for 25 percent of final energy use in the EU and to have the greatest energy-saving potential (European Commission 2011b). What is more, market and behavioural failures and other investment barriers seem more relevant in residential housing than elsewhere, notably industry and energy transformation. Firms in both sectors are exposed to competition – though perhaps not as much as one would like – and this would penalise them for systematically forgoing profitable investment in energy savings. Keay (2011b, p.6) vividly alludes to the profit motive as a driver of energy savings by recounting that "… *as long ago as the eighteenth century James Watt and Matthew Boulton, in selling their improved steam engine, did so essentially by selling its energy efficiency – that is by charging a premium to users equal to one third of the saving in fuel costs compared to an atmospheric engine*". In a similar vein, he stresses the scope for energy service companies and energy performance contracts to identify and profitably exploit energy-saving opportunities. The public sector is another domain with untapped energy savings – as argued by Schleich (2007), for instance. Like in the residential housing sector, obstacles to energy savings include informational and behavioural problems. In addition, institutional constraints hinder energy savings – for instance, if those who save energy (*e.g.* a faculty in a public university) are not rewarded, perhaps even penalised if savings today result in lower budgetary allocations tomorrow. In sum, while there might be untapped energy savings across the economy, zooming in on the residential housing sector is especially illustrative.

In Table 4, the red and orange columns signal, respectively, primary and secondary obstacles to residential energy savings – as identified in section 3.2 and summarised in Table 1. Moreover, reflecting the findings of section 3.3 (summarised in Table 2), Table 4 shows command-and-control, nudge, and non-market supply as primary solutions to informational and behavioural problems.

As a lead into discussing Table 4, it helps to recap the main insights from section 3.3. To start with informational and behavioural problems, they call for:

- Public information campaigns and projects that demonstrate the performance of energy-saving technologies – both included in Table 4 under non-market supply of information on energy-saving options;

- Energy passes for houses and apartments and energy labels for household appliances – measures falling under command-and-control in Table 4;

- Utility companies to be required to provide more timely and easier-to-process information (command-and-control) possibly combined with hitherto underexploited efforts to nudge people into investing in energy savings.

Information campaigns, energy passes, energy labelling and other means have become widely used in many advanced countries, including EU member states, as have subsidised energy audits that make users aware of energy-saving opportunities. By contrast, 'nudge' is only beginning to emerge as a cheap but potentially effective tool for solving informational and behavioural problems that stand in the way of investment in energy savings.

Subsidising investment in energy savings is a secondary solution for addressing informational and behavioural problems: although it encourages investment, it does not directly tackle the cause of the problem and brings problems of its own – as will be discussed below. Likewise, instructing energy suppliers to meet energy saving targets or buy white certificates from other suppliers does not go to the root of the problem – although it is often seen

Table 4: Mapping investment barriers to solutions – *Residential energy savings*

	Market failures, behavioural failures, & other investment barriers						
Problems	Externalities			Public goods	Information problems	Behavioural failures	Miscellaneous failures & barriers
	Env't (–)	Tech (+)	SoS (–)				
Solutions							
Markets							
Establishing property rights	*P*	*P*					
Creating new marketable goods	*P*		*P*		*S*	*S*	
Incentives							
Taxes	*P*		*P*				
Subsidies	*S*	*P*	*S*	*S*	*S*	*S*	*S*
Rules							
Frameworks	*P*	*P*	*P*	*P*	*P*	*P*	*P*
Command & control	*S*		*S*		*P*	*P*	
Nudge					*P*	*P*	
Enhanced appraisal					*P*		*P*
Insurance					*P*	*P*	*P*
Non-market supply			*S*	*P*	*P*		*P*

■ (red) = Primary failure or barrier
■ (yellow) = Secondary failure or barrier
P = Primary solution.
S = Secondary solution.

Env't stands for environmental externalities, notably the climate-change externality of greenhouse-gas emissions. *Tech* stands for technology externalities, *i.e.*, knowledge spillovers. *SoS* stands for security-of-supply externality. The + sign and the – sign in columns (1) to (3) indicate, respectively, positive and negative externalities.

as the most cost-effective way to meet a given energy-saving target. Setting 'minimum' energy efficiency standards is not a primary solution to informational and behavioural problems either, but it is a relatively non-intrusive measure that lessens their consequences.

Turning briefly to the climate-change externality and the security-of-supply externality, recall that they are not caused by energy use *per se*. Rather, they are caused by the use of fossil fuels and imported gas and oil, respectively, and the best way to address them is carbon pricing and – though perhaps not feasible under WTO trade rules – a penalty on imported oil and gas. With this in mind, the primary solutions (to problems of secondary importance from an energy-saving perspective) featuring in Table 4 must not be understood as coming on top of those discussed in the context of low-carbon investment. Rather, the stringency of the cap on carbon emissions, the carbon tax rate and – if imposed – the penalty on imported oil and gas ought to reflect the external damage associated with the use of high-carbon fuels. That said, the ensuing increase in the relative price of high-carbon fuels will encourage not only a switch towards low-carbon energy resources but energy savings, too.

The reasoning developed so far does not suggest a leading role for subsidising energy savings and mandating them – not even if the latter are tradable. The main argument up to this point has been that such solutions do not tackle the underlying informational and behavioural problems but merely counteract their consequences. Subsidies have the additional disadvantage of creating a free-rider problem as they benefit investors (*i.e.* residential property owners and tenants) who might have invested even without subsidies. Linares and Labandeira (2010) cite a number of studies that validate the empirical relevance of the free-rider problem. Offering investors a free ride is unwise at any time, but it is especially costly in times of tight fiscal constraints. Another drawback of subsidies is that they lower the carbon price and, thus, the viability of low-carbon investment when subsidies target energy governed by cap-and-trade – electricity presently being the main example (see Box 4 in chapter 4). That said, a case for subsidies can be made when they directly or indirectly benefit low-income households. In fact, climate action that makes prices reflect the true economic cost of energy disproportionately burdens the poor and, thus, there is reason to cushion the impact of higher prices on them by, among other things, subsidising their investment in energy savings. Moreover, rather than subsidising investment as such, one could argue for time-bound, moderate subsidies aimed at lowering the transaction cost of bringing together energy services companies and potential clients and, thereby, helping to develop a still nascent market for energy services.

In practice, the case for subsidies implicitly rests on two assumptions: profitable but unexploited energy savings are big and information campaigns, energy passes and labelling and 'nudges' are not forceful enough to make energy savings reach their potential. This could also be a justification for tradable energy-saving obligations (*i.e.* white certificates), which – in contrast to subsidies – would not require budgetary funds. White certificate schemes currently exist in a number of countries – including France, Italy and the United Kingdom – and although they do not directly address the causes of underinvestment in energy savings, they moderate their consequences. For tradable obligations to be an economically efficient tool (and not only a cost-effective one to reach a given target), one would need to know how large are the unexploited savings and, thus, how ambitious should be the savings target. For if the target exceeds the true energy-saving potential, people would be forced into savings they consider too costly. Against this background, moderate targets in a scenario of seemingly big, unexploited energy savings could be a strategy to gradually close the energy-savings gap. But is the gap indeed big?

The notion of big, profitable but unexploited energy savings owes a lot to McKinsey & Co (2009), which lists a variety of residential energy-savings options as mitigation measures that would incur negative cost. That is, McKinsey & Co consider them profitable even in the absence of a carbon price. A seemingly huge potential for profitable energy savings is a riddle, suggesting two explanations: first, there are indeed substantial informational and behavioural problems that even information campaigns, energy labelling and so on cannot do away with; second, the energy-savings potential is grossly overestimated, implying there is no great need to boost investment in energy savings. This is not the place to explore these issues in any detail,[53] but it is clear that stringent energy-saving targets and/or generous subsidies for investment in energy savings must assume that the saving potential is big, primary solutions to informational and behavioural problems are inadequate, and not enough can be expected from carbon pricing – either because the price signal is not made sufficiently strong or it is ineffective because of informational and behavioural problems.

In sum, searching for primary solutions to primary problems that cause underinvestment in energy savings suggests three insights. For a start, as informational and behavioural problems are the main reasons for underinvestment, the best policy response is to make more information available – through non-market supply of information and regulation that makes the private sector reveal its information. Second, subsidizing investment in energy savings does not tackle the cause of the problem, rewards free-riders, undermines carbon prices, and consumes scarce budgetary resources. That said, a case can be made for subsidizing investment in energy savings of low-income households to help them cope with an increase in energy prices, which inevitably results from climate action based carbon pricing. Third, nudging people into energy savings they would otherwise not make because of informational and behavioural problems is a yet under-explored and underused measure to boost energy savings.

3.4.3 Investment in adaptation

Reflecting the classification used here, it makes sense to examine, first, private adaptation investment and, then, public adaptation investment. For private adaptation, the conceptual framework behind Table 1 and 2 simplifies to the template shown in Table 5 – with policy failures subsumed under the heading 'miscellaneous'. Likewise, for public adaptation investment, Table 6 emerges as a suitable guide for analysing solutions to the underinvestment problem. The following narrative on the relevant table entries partly draws on Kahn (2010) and Konrad and Thum (2012).

Private adaptation

To recall, faced with a changing climate, self-interested and rational people would seek a proper mix between adaptation (that is, self-protection), insurance and coping with climate-change impacts retroactively. In real-world economies, however, people forgo optimal choices – mainly because of informational and behavioural problems (as set out in section 3.2). Moreover, even if people chose rationally, their choice might not be optimal from society's viewpoint – mainly because of unintended consequences of well-intended government policies. All in all, informational and behavioural problems and policy failures are likely to bias choices against adaptation and insurance. A central question, then, is what governments can do to overcome informational and behavioural problems and to ensure that their policies function as intended.

Providing climate-change information is one of the most obvious tasks for governments. Table 5 shows this as non-market supply in response to informational problems. Systematic government action in this field is underway – see *UKCIP*, *KomPass Kompetenzzentrum Klimafolgen und Anpassung,* and the *European Climate Adaptation Platform*.[54] In addition to information on climate change, knowledge of effective adaptation measures has public-good characteristics and, thus, there is a rationale for governments to acquire and disseminate it. However, while governments are typically better informed about climate change and adaptation measures than citizens, the latter probably know better how to make use of this information. But it is true, too, that people will most likely not act on this information in a socially optimal manner if they anticipate generous help from governments after climate events have hit. Before substantiating this proposition, it is useful to briefly discuss how command-and-control contribute to overcoming information problems.

As described in section 3.2.2 of this chapter, the split-incentive problem (itself a consequence of asymmetric information) could be one reason for too little adaptation investment, notably in the residential housing sector. Similar to requiring energy passes and labels, which address underinvestment in energy savings due to the split-incentive problem, one could envisage adaptation passes and labels. Adaptation passes for houses in a flood-prone area, for instance, could inform whether houses feature airbrick covers, door-guards, drainage bungs, non-return valves, and other flood protection measures. In addition, adaptation passes could inform on the frequency and extent of flooding in recent decades and the insurance premiums for houses with and without flood protection. Requiring adaptation passes and labels is a relatively non-intrusive command-and-control measure aimed at revealing information on how climate resilient residential property is, encouraging adaptation investment whenever it is worthwhile.

Bringing about the right level of insurance is another key element of a policy strategy aimed at promoting efficient adaptation. To see why, imagine that people in flood-prone locations are aware of climate risks, but choose to neither adapt nor insure because they hope that governments will help them out when disaster strikes. In principle, governments could prevent such behaviour by announcing that there will be no bailouts. Such an announcement is not credible, however, as governments will come under

Table 5: Mapping investment barriers to solutions – private adaptation

	Market failures, behavioural failures, & other investment barriers						
Problems	Externalities			Public goods	Information problems	Behavioural failures	Miscellaneous: Government bailout
	Env't (–)	Tech (+)	SoS (–)				
Solutions							
Markets							
Establishing property rights	*P*	*P*					
Creating new marketable goods	*P*		*P*		*S*	*S*	
Incentives							
Taxes	*P*		*P*				
Subsidies	*S*	*P*	*S*		*S*	*S*	*S*
Rules							
Frameworks	*P*	*P*	*P*		*P*	*P*	*P*
Command & control	*S*		*S*		*P*	*P*	
Nudge					*P*	*P*	
Enhanced appraisal					*P*		*P*
Insurance					*P*	*P*	*P**
Non-market supply			*S*		*P*		*P*

(yellow) = Secondary failure or barrier
P = Primary solution.
S = Secondary solution.
* = Primary solution when people bank on government bailout in a climate-risk event.

Env't stands for environmental externalities, notably the climate-change externality of greenhouse-gas emissions. *Tech* stands for technology externalities, *i.e.* knowledge spillovers. *SoS* stands for security-of-supply externality. The + sign and the – sign in columns (1) to (3) indicate, respectively, positive and negative externalities.

political pressure if they refused to help those hit by seemingly unforeseen floods, storms and so on. That people do not suffer because of bad luck but because they chose not to prepare for it will most likely cut little ice.[55]

Restrictive zoning codes – a command-and-control measure that excludes excessively risky locations from property development – are the most obvious means to lessen the bailout dilemma. Likewise, governments could set building codes so as to reduce damages in the event of climate-change impacts.

In addition, to prevent people in vulnerable locations from banking on government bailouts, they could be required to purchase at least some insurance. If insurers are free to charge high insurance premiums for those who have not invested in adaptation and low premiums for those who have, mandatory insurance encourages adaptation as it buys lower insurance premiums. And then, insurers should be free to set high insurance premiums for property in locations with a high exposure to climate risk, thereby reducing the likelihood that high-risk locations are chosen in the first place. By extension, governments must refrain from regulation that prevents insurers from setting insurance premiums that penalise lack of adaptation and choice of high-risk locations. But for all this to work well it is important, too, that competition policy prevents insurers from exploiting customers that are obliged to purchase insurance. In a similar vein, as a *quid pro quo* for creating demand for insurance, insurers could be required to publish their information on country-wide and location-specific climate risks.

Even if governments could credibly commit to a no-bailout, a rationale for mandatory insurance possibly follows from adverse selection – one of the consequences of asymmetric information. The upshot of adverse selection is that insurers offer too little insurance, at too high premiums, to high-risk customers only. This is because insurers cannot easily tell apart low-risk from high-risk customers. Introducing adaptation passes lessens the problem since they would reveal potential customers who have invested in self-protection. But the adverse selection problem does not fully go away since customers still know more than insurers about their exposure to climate risks.

Assume away the bailout problem and adverse selection, an argument for mandatory insurance remains if people choose too little insurance and adaptation – or both – because of bounded rationality, misperception of risk and limited actuarial experience. As before, mandatory insurance combined with insurance premiums that reward self-protection encourage investment in adaptation. An intervention that is less intrusive than mandatory insurance is subsidised insurance in combination with insurance premiums that reward self-protection, but subsidised insurance puts a burden on government budgets.

This disadvantage also applies to subsidies for adaptation investment, but as Table 5 recalls, a subsidy is in any event a secondary solution to informational and behavioural problems as it does not address their underlying cause. From a practical viewpoint, one drawback of subsidies is that they waste funds on free-riders, that is, people who would have invested in adaptation even without subsidies. Another challenge is that to get the subsidy right, one would need to know the magnitude of the investment gap and what is takes to close it.

Though largely left out of the analysis offered here, it is worth emphasising that fairness and equity could argue for subsidising insurance for the poor and/or subsidising their investment in adaptation.

In light of technology externalities, subsidies could also be justified to foster investment in research and development of adaptation goods and services – for instance, more energy-efficient air conditioning (of which more will be needed with rising temperatures) and desalination plants (of which more will be needed with increasing scarcity of freshwater). But as with investment in low-carbon technologies and in energy savings, it is hard to argue that technology externalities hinder adaptation goods and services more than other goods and services. In fact, Kahn (2010, p.8) offers a refreshingly optimistic outlook, noting that "*the innovative capitalist culture will allow us to make a Houdini-style escape from climate change's most devastating impacts*". To illustrate the point, he imagines a firm that develops a super-efficient air conditioner, thereby capturing a huge and, because of rising energy prices, profitable world market. But Kahn also stresses that his outlook presupposes that governments let energy prices rise to clear markets because only high energy prices reward investment in highly energy-efficient technologies.

Finally, Table 5 is silent on the possibility of using market mechanisms as a solution to underinvestment in adaptation. One example would be a mechanism under which beneficiaries of flood-water protection through wetlands pay the owners of wetlands. The potential role of markets in this domain is under-researched, as pointed out by Butzengeiger-Geyer *et al.* (2011). Drawing on lessons learned from using markets in mitigation, the authors explore the potential role of market mechanisms in adaptation and suggest avenues for future research. This research can be seen as part of the research on payments for ecosystem services.

To wrap up, mainly because of informational and behavioural problems and policy failures, people might choose an inefficient mix of adaptation, insurance, and climate risk neither reduced nor insured. Zoning restrictions, building codes and mandatory insurance can make things better when the cause of the problem is informational and behavioural failures and hope for government bailouts. Equally important, governments must avoid interventions – such as ceilings on insurance premiums – that effectively discourage investment in adaptation. But it is true, too, that there is a need to step up competition policy and other regulatory measures if people are forced to insure when they would not voluntarily.

A key insight to take away from this analysis is that policies must not distort people's choices – choices that would imply too much climate risk neither avoided nor insured against. Perhaps surprisingly, public adaptation investment might also be distorting, as will be explored next.

Public adaptation

By definition, public adaptation is non-market supply of public goods, and as Table 6 recalls, this is a primary solution to the public-good market failure. Prominent examples include investment in sea-level defences, river-flood protection, and fresh-water supply. There are many challenges in designing, financing, implementing and operating public adaptation investments. That said, from a broad policy perspective a crucial challenge is to ensure congruence between those who benefit from, pay for and decide on both adaptation investment and help after climate impacts have hit. To see why, consider three problems following from a lack of congruence.

First, there could be a bailout game playing out between different levels of government. Most public adaptation investment needs arise at the local/regional level rather than the national level of a country. The incentive of local governments to invest in adaptation is stifled if they anticipate help from higher levels of government in a climate-risk event. If higher levels could credibly commit not to come to the rescue, there would be no bailout problem and local governments would adapt as much as is in the interest of their citizens – subject to the caveat that citizens pay for the investment (more on this below). As higher levels of government cannot credibly

Table 6: Mapping investment barriers to solutions – *Public adaptation*

	Market failures, behavioural failures, & other investment barriers						
Problems	Externalities			Public goods	Information problems	Behavioural failures	Miscellaneous: Intergovernmental bailouts
	Env't (–)	Tech (+)	SoS (–)				
Solutions							
Markets							
Establishing property rights	P	P					
Creating new marketable goods	P		P		S	S	
Incentives							
Taxes	P		P				
Subsidies	S	P	S	S	S	S	S
Rules							
Frameworks	P	P	P	P	P	P	P
Command & control	S		S		P	P	
Nudge					P	P	
Enhanced appraisal					P		P
Insurance					P	P	P*
Non-market supply			S	P	P		P

![red] = Primary failure or barrier
![yellow] = Secondary failure or barrier
P = Primary solution.
S = Secondary solution.
* = Primary solution when lower level of government banks on bailout by higher level of government in a climate-risk event.

Env't stands for environmental externalities, notably the climate-change externality of greenhouse-gas emissions. *Tech* stands for technology externalities, *i.e.* knowledge spillovers. *SoS* stands for security-of-supply externality. The + sign and the – sign in columns (1) to (3) indicate, respectively, positive and negative externalities.

commit, however, one could argue in favour of making the participation of local governments in nationwide risk-sharing/insurance arrangements mandatory.

Second, public adaptation could crowd out more cost-effective private adaptation. Imagine a coastal community that wants to attract economic activity by developing industrial real estate and assume that an anticipated sea level rise makes it a must to invest in flood defences. An investment appraisal shows that the benefits (*B*>*0*) exceed the costs (including flood defences) of developing the estate and, thus, development receives the go-ahead. But is this the right decision?

To find out, one must consider what would have happened without the real estate development. As the underlying economic activity is assumed to be profitable (*B*>*0*), it would have emerged elsewhere. More specifically, with no additional flood defences anywhere, the activity would have taken roots in areas not exposed to a rising sea level or climate risks in general. Ignoring regional policy concerns, the location of activity in areas not exposed to climate change would have been a better outcome since it would have generated the same benefits without the cost of flood defences.

Finally, there is – paradoxically only at first glance – the risk that public adaptation increases rather than reduces people's exposure to climate-change impacts. The economic activity considered in the previous illustration would have also taken root in areas not exposed to a rising sea level, if beneficiaries had to contribute to the cost of flood defences in locations where they are necessary. By extension, if they do not contribute, public adaptation investment might inadvertently attract them to locations with greater climate-change impacts. The more general point here is that, unless beneficiaries pay, defensive adaptation investment attracts households and firms to locations where they should not settle in the first place – and certainly not with more climate change to come.

Three conclusions thus emerge. First, choice of location and migration is an obvious and cost-effective adaptation to climate change and humans have used it since time immemorial. Second, while it is pertinent for governments to examine how public investment could contribute to climate-change adaptation, it is equally important that public policies do not inadvertently bias the mix of private and public adaptation against more cost-effective private choices. Third, welfare-reducing outcomes are more likely the less the beneficiaries of public adaptation pay for it – because, for instance, the level of government implementing the investment can draw on grant finance from higher levels of government.[56]

Table 6 signals enhanced appraisal, along the lines of NPV+ (see section 3.3), as a means of improving information on the costs and benefits of public adaptation investment, which intends to prepare for not one but possibly many futures given the uncertainty about climate-change impacts. In these circumstances, NPV+ might show that investing moderately and flexibly is better than investing massively (as illustrated in the annex). But NPV+ might also suggest – contrary to standard analysis – that there is merit in delaying investment (also illustrated in the annex). As a possible tool for appraising public adaptation investment, NPV+ is advocated by HM Treasury (2009) and it has been used for the appraisal of such investment by Dobes (2010), Linquiti and Vonortas (2011) and Woodward *et al.* (2011), for instance.

That adaptation is meant to prepare for many possible scenarios in a distant future invites a closing comment on adaptive capacity and its link to economic growth. Fankhauser and Soare (2012) emphasise the importance of adaptive capacity in the face of many possible futures, and Konrad and Thum (2012) stress that economic growth supports a country's adaptive capacity. It follows that growth-promoting policies might be far more important than specific adaptation investments. To make their point, Konrad and Thum offer a compelling thought experiment (p.21): "*Suppose our ancestors in the year 1920 had considered climate change in the early twenty-first century and discussed specific types of pro-active adaptation investments. What would these have been? And would they be adequate* ex post*, given a sector composition of the economy today that was completely unforeseen at that time?* Ex post*, a pro-growth policy was probably the best adaptation investment they could have done*."

3.5 Conclusions

This chapter developed and applied a conceptual framework for analysing why there might be too little climate investment and how to boost it. A key feature of this framework is the distinction between primary and secondary reasons for underinvestment and the distinction between primary and secondary solutions to tackling underinvestment problems. Five main messages derive from this analysis – some of them well known, while others are perhaps surprising.

First, the climate-change externality of using high-carbon fuels and the global public-good challenge of cutting carbon emissions are the main obstacles to low-carbon investment. Carbon pricing is best to boost low-carbon investment and more investment can be expected with a stronger, long-term price signal applied to a wider set of carbon emissions than those currently governed by EU ETS. To successfully address the global public-good challenge, an international climate agreement is indispensable.

Second, informational and behavioural problems are the major deterrents to investment in energy savings. The best policy response is to make more information available – through non-market supply of information and regulation that makes the private sector reveal information that boosts investment in energy savings. By contrast, subsidising investment in energy savings does not tackle the cause of the problem, rewards free-riders, undermines carbon prices and consumes scarce fiscal resources. Nudging people into energy savings they would otherwise not make because of informational and behavioural problems is a yet under-explored, potentially inexpensive measure to encourage energy savings.

Third, informational and behavioural problems might stifle, too, private investment in adaptation, but they are probably of secondary importance. Of greater importance is inefficient adaptation due to possible policy failures – including unintended consequences of well-intended government intervention. Good policies include zoning restrictions, building codes, mandatory insurance and limits to government help in climate-risk events. Furthermore, there is, of course, the public-good market failure that calls for public investment in adaptation. That said, to ensure that public investment in adaptation is economically efficient and does not crowd out more cost effective private adaptation, it is important to levy the taxes needed to finance the investment on firms and households that benefit from it. More fundamentally, pro-growth policies are perhaps the best adaptation investment societies can make given the positive link between economic growth and societies' adaptive capacity.

Fourth, Europe's climate-change policy landscape has developed and changed since the 1990s. Similar to a garden where different trees, bushes and flowers were planted at different points in time, the climate-change policy landscape would benefit from a little pruning. In particular, economic efficiency and fiscal constraints suggest an overhaul of support for low-carbon investment as put in place before the start of EU ETS. Support in favour of emission reductions governed by cap-and-trade no longer lowers emissions, but it unduly weakens the carbon price signal and employs resources that could be put to better use – for climate action and other laudable causes. Needless to say, there continues to be an argument for well-targeted and measured support in response to technology externalities created by low-carbon investment. And it is clear that the economic and fiscal arguments for rationalising the policy landscape as inherited from the past become stronger as and when more emissions are brought under EU ETS.

Finally, the mapping of primary solutions to primary underinvestment problems suggests harmony between solutions of primary importance and those that are fiscally neutral – if not benign as in the case of carbon pricing. And the opposite holds, too: solutions of secondary importance often impose a fiscal burden that most primary solutions do away with. The good news, then, is that there is no conflict between well-targeted climate policy and fiscal consolidation.

Annex: NPV+ or the real option approach to investment

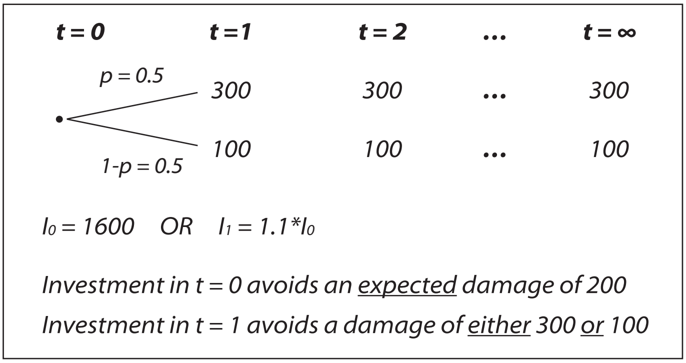
What has been coined NPV+ for the purpose of this report is commonly known as the real option approach to investment. The seminal work in the field is Dixit and Pindyck (1994) and Trigeorgis (1996). Publications targeting project appraisal practitioners include Amram and Kulatilaka (1999), Copeland and Antikarov (2001), and Kodukula and Papudesu (2006). The reason for calling it NPV+ here is to unmistakably signal that the real option approach is not meant to replace NPV as a decision making rule. Rather, it builds on NPV as derived from standard discounted cashflow analysis and extends this NPV by explicitly valuing features of an investment that standard analysis overlooks or values incorrectly. That said, NPV+ does not always inform better than standard NPV (NPV^S). This raises the question when NPV+ is a more useful tool than NPV^S and, by extension, when NPV^S adequately values an investment.

The answer comes in two parts. NPV+ might be more useful when investment can be deferred; is largely irreversible; is surrounded by uncertainty; and – perhaps most importantly – can be modified in light of how uncertainty (partly) resolves over time. By contrast, NPV^S is adequate when it suggests either a clearly profitable or clearly unprofitable investment. In these circumstances, additional insights from NPV+ will not turn a poor investment into a good one, and *vice versa*, but it can tilt the balance for borderline projects. In sum, NPV+ is a helpful appraisal tool when the investment has the characteristics set out above and when standard analysis suggests that its viability is neither clearly strong nor clearly weak.

The main purpose of what follows is to illustrate the difference and the link between NPV+ and NPV^S. The illustration, inspired by Dixit and Pindyck (1994), is for an investment in climate-change adaptation, more specifically, a river-flood protection project.

Suppose the project can be implemented either today ($t = 0$) or tomorrow ($t = 1$). It is certain that the climate will change between today and tomorrow. However, the extent of climate change is uncertain, but it will be known in $t = 1$. There is a 50-percent chance of big climate change, causing damage of

300 in the absence of flood protection. But there is also a 50-percent chance of small climate change, causing damage of only 100. The expected damage in the absence of flood protection is thus 200. Avoided damages when there is flood protection constitute the benefit of the investment. After tomorrow ($t \geq 2$), there is no uncertainty and the damage without flood protection will either be 300 or 100, depending on how uncertainty resolves in $t = 1$. If investment takes place today ($t = 0$), investment costs are $I_0 = 1600$. If deferred to tomorrow ($t = 1$), investment costs are 10 percent higher ($I_1 = 1.1{*}I_0$). The discount rate is assumed to be 10 percent, too. For simplicity, project operating costs are zero and its lifespan is infinite. Below is a graphical representation of the investment situation (with p and $1\text{-}p$, respectively, indicating the probability of big and small climate change).



The standard net present value of investment in $t = 0$ is:

(1) $$NPV_0^S = -1600 + \sum_{t=1}^{\infty} \frac{200}{1.1^t} = 400$$

Thus, investing seems to be worthwhile. However, consider the option of investing tomorrow, that is, once uncertainty about the extent of climate change is resolved. If it turns out that damages in the absence of the project are modest (100), it would not be worthwhile to invest (plugging in 100 instead of 200 in (1) suggests a negative net present value). By contrast, it would be worthwhile if damages are 300 since from the perspective of today ($t = 0$), the standard net present value of investing in $t = 1$ is

(2) $$NPV_1^S = 0.5^*\left(-\frac{1.1^*1600}{1.1} \sum_{t=2}^{\infty} \frac{300}{1.1^t} \right) = 564.$$[57]

In (2), annual benefits (=avoided damages), amount to 300 as investment is contingent on there being big climate change, and as this happens with probability 0.5, the difference between discounted benefits and investment cost is multiplied by 0.5.

Comparing (1) and (2) suggests that the optimal investment decision is to wait until tomorrow and then invest only if climate change is big. The reason why deferral makes sense is straightforward: the decision to invest tomorrow is contingent on there being a big change in climate (300) and, thus, investment takes place only when project benefits are large. By contrast, an investment today might end up in a world with only small climate change (100) for which flood protection would not be worthwhile. In essence, delaying investment until uncertainty has resolved escapes the downside risk of investment (*i.e.* low project benefits when the change in climate is small) while maintaining the upside chance.

The results captured in (1) and (2) can be used to introduce the NPV+ concept. According to (1), investing today would be worthwhile if the investment cannot be delayed. But as it can be delayed, investing today destroys the option of investing tomorrow. From today's perspective, the value of this option is given by (2). If waiting is possible, a correct calculation of the net present value of investing today treats the value of the option destroyed as an opportunity cost, and including this opportunity cost yields the following NPV+ for an investment today ($t = 0$):

(3) $$NPV_0^+ = NPV_0^S - NPV_1^S = 400 - 564 = -164$$

Thus, accounting for the opportunity cost of investing today, investing today is not a good idea.

Three remarks should be made. First, given the simplicity of the example, NPV+ does not apply to investing tomorrow because there is no uncertainty after tomorrow and the option of further delaying the investment was ruled out. Second, for the situation considered here, the + in the NPV+ is negative.

This is because the relevant choice is one of timing, and investing today inevitably destroys an option that either has a positive value or a value of zero. How investing today can create rather than destroy an option will be discussed below. Third, even for pure timing decisions, NPV+ does certainly not imply that delaying investment makes sense under all circumstances. This will be explored next.

One simply needs to ask whether there is a lower limit I_0^L that would make investing today outperform investing tomorrow if investment costs in $t = 0$ are below that limit. As can be derived from (1) and (2), this threshold is $I_0^L = 1273$. For further insight, suppose $I_0 = 1000$. (1), (2), and (3), respectively, then yield $NPV_0^S = 1000$, $NPV_1^S = 864$,[58] and $NPV_0^+ = 136$. This signals a go-ahead for investing today.

As uncertainty is one of the characteristics that makes NPV+ especially useful, it is intriguing to see how greater uncertainty effects the decision in the previous paragraph (that is, for $I_0 = 1000$). To this end, assume that big climate change is 350 (up from 300) and small climate change is 50 (down from 100). To examine greater uncertainty in isolation, the change in uncertainty has been chosen so that the expected climate change remains 200. The graphical illustration below pictures the new investment situation.

t = 0	**t = 1**	**t = 2**	**...**	**t = ∞**
p = 0.5	*350*	*350*	...	*350*
1-p = 0.5	*50*	*50*	...	*50*

$I_0 = 1600$ *OR* $I_1 = 1.1*I_0$

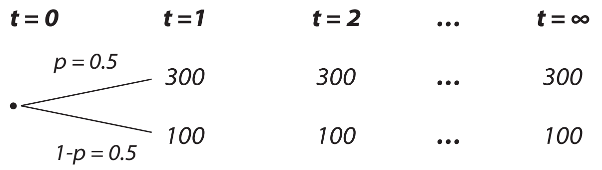
Investment in t = 0 avoids an <u>expected</u> damage of 200

Investment in t = 1 avoids a damage of <u>either</u> 350 <u>or</u> 50

Using equation (1), (2), and (3), respectively, yields $NPV_0^S = 1000$, $NPV_1^S = 1091$, and $NPV_0^+ = -91$. Hence, greater uncertainty – as modelled here – leaves NPV_0^S unchanged, but it increases NPV_1^S in a way that makes it profitable to delay the investment. This is because delay avoids a downside risk that has increased (50 instead of 100) while keeping the option to benefit from a greater upside chance (350 instead of 300).

To shed yet more light on the option to defer, it is instructive to seek for an upper limit on investment cost in $t = 1$ (I_1^U) that leaves investing tomorrow marginally better than investing today. Assume again $I_0 = 1600$. Setting the right-hand side in (2) equal to 400, replacing 1.1*1600 by I_1^U, and then solving for I_1^U yields $I_1^U = 1927$. That is, deferral makes sense as long as investing in flood protection tomorrow costs less than 1927, which compares to 1600 for an investment in $t = 0$. The reason why a more costly investment tomorrow can be more profitable than a cheaper investment today is that tomorrow's investment happens only when climate change is big (300) and, thus, project benefits are large. By contrast, an investment today might end up in a world with only small climate change (100) for which flood protection would not be worthwhile. The advantage of deferral vanishes for $I_1^U > 1927$.

So far, the illustration evolved around the option to defer an investment. This is the easiest way to introduce the NPV+ concept. But the option to defer is also the most basic option that comes with virtually all investment opportunities. Another important option that an investment opportunity might entail is the option to expand: in its simplest form, an investment today creates the option to expand the investment tomorrow. Continuing with the flood protection example, the following illustration considers an investment of 1050 in $t = 0$ that would make it possible to avoid climate change damages of 100 from $t = 1$ onwards. As before, climate change uncertainty resolves in $t = 1$ and the climate change is either big (300) with probability 0.5 or small (100) with the same probability. If it is big, the initial investment can be expanded at a cost of 605. In combination with the initial investment, this follow-up investment would make it possible to avoid climate-change damages of 300 from $t = 2$ onwards. Thus, upgrading the initial investment would prevent an additional damage of 200. The following diagram illustrates the situation.



$I_0 = 1050$ $I_1 = 605$

Investment in t = 0 avoids damage of 100

Investment in t = 1

- *Can be made only if investments in t = 0 was made*
- *Is considered only if climate change is 300*
- *Avoids additional damage of 200*

The standard net present value of the first-stage investment is

$$(4) \qquad NPV_0^S = -1050 + \sum_{t=1}^{\infty} \frac{100}{1.1^t} = -50$$

The investment would thus not be worthwhile. However, investing today creates the option to expand flood protection in case of big climate change. Viewed from today, the standard net present value of the follow-up investment is

$$(5) \qquad NPV_1^S = 0.5 * \left(-\frac{605}{1.1} + \sum_{t=2}^{\infty} \frac{200}{1.1^t} \right) = 634.$$

In (5), the multiplication by 0.5 of the term in brackets is because the investment will only be made with probability 0.5. With the same probability there will be no investment since investing is not sensible when the change in climate turns out to be small. Since the value of 634 is made possible by the initial investment, the merits of this investment should be reconsidered. This is what *NPV+* does. More specifically, in addition to its own stream of net benefits (which is negative in this case), the initial investment creates the option for a follow-up investment, and the value of this option is given by (5). In sum:

$$(6) \qquad NPV_0^+ = NPV_0^S - NPV_1^S = -50 + 634 = 584$$

The conclusion is that instead of rejecting the investment because of $NPV_0^S < 0$, it is worth embarking on because of the large option value it creates.

It is instructive to return to the timing problem discussed above. The present-value cost of the combined investment is $1050 + 605/1.1 = 1600$. Suppose the investment is carried out full scale in $t = 0$. According to (1) $NPV_0^S = 400$. This would erroneously suggest that full-scale investment is worthwhile since it ignores that full-scale investment destroys the option to expand. NPV+ recognises this by treating 634 (from equation (5)) as an opportunity cost, showing that the correct value of the full-scale investment is $NPV_0^+ = 400 - 634 = -234$. Thus, the flood protection project should not be carried out in one sweep but staged, with the first stage creating the option to expand – an option that will be exercised only in case of big climate change.

It is instructive, too, to determine the investment cost that the expansion stage could afford while leaving the staged investment marginally better than full-scale investment in $t = 0$. Setting the right-hand side of (5) to 450, substituting I_1^U for 605, and then solving for the investment cost yield $I_1^U = 1010$. Thus, as long as the present value of the combined investment cost of the staged investment is smaller than $1050 + 1010/1.1 = 1968$, staging the investment is better than full-scale investment of 1600.

The illustrations are so simple that is possible to calculate NPV+ on the basis of two standard net present value calculations (equation (3) and (6)). For real-world investment situations, more elaborate solution methods must be used. Providing even a sketch of them would go beyond what can be achieved here (for a hands-on introduction, see Kodukula and Papudesu (2006), for instance). Suffice to note that there are three broad methods. One of them rests on a dynamic programming approach that lays out the evolution of uncertainty over the life of the option to investment and calculates NPV+ in a backward recursive fashion. The upper parts of the diagrams above show the evolution of uncertainty over one period, with uncertainty evolving in a binomial way (that is, the uncertain variable – here climate change – takes one of two values). In practice, the option to invest might exist over many periods and the evolution of uncertainty can be multinomial. For practical applications, the dynamic programming approach – often simply referred to as binomial method – is the most suitable of the three methods (the other methods – not discussed here – rest on the Black-Scholes option pricing model and Monte Carlo simulations, respectively). It offers more flexibility than other methods. Perhaps more important, it uses a spreadsheet framework that is as much a tool for thinking about investment decisions as finding optimal ones and makes transparent how optimal investment decisions are developed rather than taking them out of a 'black box'.

In addition to the option to defer and to expand, an investment opportunity might entail many other options – such as the option to contract, abandon, choose and grow – and there can be multiple interacting options. Options to grow are similar to options to expand, but they involve more than simply the option to expand the scale of the initial investment. Consider floating family houses – pioneered in the Netherlands as an answer to rising sea levels and erratic floods. The initial investment to design, build and market them can be seen as an opportunity that creates a number of follow-up options: reduce the cost of houses and improve their quality; broaden from family houses to other aqua-architecture such as hospitals, schools, churches and so on; and adapt the concept so that it can be applied elsewhere in the world. The general point is that an initial investment might be a springboard for follow-up investments that could not be made without the initial investment, the value of the initial investment is not determined by its expected direct cashflow but by the future growth opportunities it might unlock, and NPV+ allows these opportunities to be valued and, thereby, gives a better picture of the true viability of the initial investment (Trigeorgis 1996).

Having explained the thrust and merits of NPV+, it is fair to discuss a few of its limits. For a start, investing time and effort in moving from standard analysis to NPV+ can be spared if the former comes with a clear-cut verdict – positive or negative. And then, valuing options embedded in investment opportunities is useful only if there is willingness to exercise options when it is advantageous to do so. There is also a rather fundamental concern. The methods for calculating NPV+ rest on models to price options on financial assets. It has been observed that such models make assumptions (that is, there are 'no arbitrage opportunities' and there exists a 'replicating portfolio') that seem implausible in the context of real assets, that is, the kind of investment considered here. Acknowledging this challenge, Kodukula and Papudesu (2006), discuss how project appraisal practitioners try to overcome it. Finally, NPV+ requires more information than standard analysis. In particular, one needs a good idea of how uncertainty evolves over time – ideally based on empirically estimated volatilities of relevant variables. Indeed, as the example above has shown, NPV+ results are sensitive to the degree of uncertainty. This might be a problem when volatilities are not based on sound empirical evidence but assumptions – even plausible ones. That said, it is not obvious why one should worry more about assumed volatilities than about other assumptions entering standard NPV analysis. In fact, volatilities assumed for NPV+ purposes might simply bring to the fore views about uncertainty concealed in standard NPV analysis. Moreover, when NPV+ accounts for climate-change uncertainty (as in the illustrations above), all concerns about possibly wrong volatility assumptions should not be a valid reason to discard NPV+. This is because the degree of climate-change uncertainty is, by definition, assumed rather than empirically estimated and if these assumptions are accepted in the broader climate change debate, there is no reason to discard them for investment appraisal purposes.

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CHAPTER 4

Green growth and green innovation

Georg Zachmann

Chapter at a glance

Decarbonisation policies serve the primary goal of mitigating climate change. Various models confirm that the welfare-optimal scenario requires a greater decarbonisation effort than would be expected in a business-as-usual scenario. In the last decade(s) an extensive literature evolved that suggests that decarbonisation policies might – so to speak as a side benefit – also stimulate innovation and growth. This chapter begins by exploring the different channels through which decarbonisation policies might induce green growth and green innovation. The chapter then evaluates the efficiency of European decarbonisation policies in order to assess if the same level of decarbonisation might be achieved with policies that allow for a higher rate of economic growth. The chapter concludes with some proposals for decarbonisation policies that would make the achievement of the desired level of decarbonisation more growth-friendly.

Section 4.2: What are the links between decarbonisation and growth?

- An optimal decarbonisation policy is by definition welfare enhancing. However, increases in welfare do not necessarily coincide with short-term GDP growth. GDP is a gross concept that only considers the market value of inputs/outputs. For example, welfare-detrimental climate damage creates new needs that have to be met by additional production (either using under-utilised capacities or by foregoing leisure) and may increase GDP. At the same time, welfare-neutral energy savings may be production-reducing. However, policies that increase long-term economic growth typically also improve welfare. Hence policies that accommodate decarbonisation with growth are welfare enhancing.

- The quality of decarbonisation policies will closely determine the (GDP) growth impact of decarbonisation. The growth impact of decarbonisation policies depends on whether they improve overall economic policy. Decarbonisation policies can be growth friendly if they resolve existing policy or market failures that impede growth. Potential policy or market failures that can be alleviated by smart decarbonisation policies are: cyclical unemployment, growth unfriendly tax structures, unfavourable terms-of-trade, insufficient and ill-targeted innovation, insufficient aggregate investment and inadequate development policy.

Section 4.3: What is the growth impact of current climate policy?

- Current European decarbonisation policies are far from efficient – hence leaving extant growth potential untapped.

- This section identifies some major obstacles to an optimal set of decarbonisation policies: lack of a long-term signal deters investment in low-carbon technologies; fragmented global policies cause an inefficient geographical distribution of abatement efforts; overlapping policies may interact to create less-than-desired effects and raise the costs of abatement; high sectoral differences in the cost of carbon; and an overall lack of coordination, result in EU climate policies being significantly less growth-friendly than they could.

- Although unprecedented tools have been developed to combat climate change, these tools are not deployed in a manner that would achieve the full potential for concurrent green growth.

Section 4.4: What are the guidelines for growth-friendly climate action?

- Sound climate policy plays an essential role in achieving green growth and green innovation. This section proposes a set of policies that could make European decarbonisation policies more growth-friendly.
- First, a long-term challenge requires a long-term credible framework. Stepping-up the role of the ETS and reducing the micro-management of decarbonisation activities is efficiency-improving.
- Second, countercyclical timing of some of the investments needed for decarbonisation could provide a welcome stimulus for countries experiencing cyclical downturns.
- Finally, instruments for climate action should also pass a growth-friendliness test.

4.1 Introduction

As discussed in chapter 2, there are obvious trade-offs between climate mitigation, adaptation and endurance. Greater and earlier mitigation would reduce the need for adaptation and endurance, while increased adaptation would reduce the need for mitigation by making it possible to tolerate climate change-related impacts. In theory, one or more welfare maximising combinations of these three strategies, and their timings, must exist.

The optimal policy clearly depends on the measure being maximised (*i.e.* the objective function). Most economic policy makers and many economists have focused on the sum of production of goods and services (GDP), because welfare is a concept that is difficult to operationalise.[59] One should keep in mind that maximising GDP is not equivalent to maximising welfare. Take, for example, the effects of adaptation and endurance. Climate change produces new needs: a house damaged by flooding needs to be repaired (endurance) or new dykes need to be built (adaptation) to prevent damage from flooding. Those new needs are met by new production, and therefore may increase GDP. At the same time, as GDP is a 'gross' concept, it does not measure the depreciation of assets through disasters. Hence, climate change-related damages and their subsequent repair, in the short-term, even increase GDP. By contrast, measures that may slow climate change (*e.g.* energy savings) might reduce GDP by reducing inputs. This can be illustrated by a classic Robinson Crusoe economy. If Robinson Crusoe is able to reduce his oil consumption by switching off his oil lamp in daytime (this does not reduce his welfare), he will have to produce less oil. He will use a part of the freed-up time for enjoying more leisure time and a part of it for producing something else. Hence, his total production (GDP) decreases, while his welfare (additional leisure time plus some new consumer goods) increases.

In the short-term, GDP might be maximised through a low level of mitigation combined with a high level of endurance and adaptation, while long-term welfare might be maximised by the reverse. However, societal production is an important source of welfare, and unsustainable levels of production cannot continue forever. Repairing damage over and over again will consume the resources needed for investment in additional production. Hence, GDP is not a perfect indicator of economic welfare in the short-term. In the long-run, and when taking the limitations of natural resources into consideration, societal production is closely linked to welfare. Achieving decarbonisation, and thereby reducing the adverse effects of climate change, while at the same time stimulating long-term economic growth[60] and thus allowing for an increase in the level of consumption, would increase welfare.

Some economists have argued that decarbonisation might be growth-friendly (growth through decarbonisation has been termed 'green' growth)[61]. They claim that decarbonisation policies can stimulate innovation and investment, and help overcome natural resource limits. Decarbonisation would therefore be a good investment of resources, even without taking climate change into account (others have argued that decarbonisation might create jobs – a discussion we will not enter into detail in this chapter, see Box 1). The following sections analyse the conditions under which decarbonisation might indeed be accompanied by economic growth.

Box 1: The green jobs debate

There is an ongoing debate about whether decarbonisation policies can increase the level of employment. The debate has focused on the question of whether public support to green sectors can create additional jobs.

Public support to a sector might have positive employment effects for the sector. Spending public money on renewable energy in Germany is likely to generate employment opportunities in the sector. The question is if this positive employment effect compensates for the reduction in jobs in other sectors. The reduction in jobs occurs for three main reasons: *first*, the cost of public support is passed through to the economy either through new taxes or higher energy prices. This reduces overall economic activity and, hence, the total level of employment. *Second*, new employees in the green sector will not come only from the pool of currently unemployed, they will be partly recruited from other sectors. If they are highly skilled, as is the case for some engineers switching to the renewables sector, they might be difficult to replace in their former sector. The other sector might be forced to reduce output and lay-off low-skilled staff due to shortages of skilled labour. Third, decarbonisation policies are characterised by an increase in investments in physical capital. This would increase the cost of capital for all sectors and might therefore reduce overall output and employment.

Because of these three indirect effects, decarbonisation policies will likely lead to a shift in employment from high-carbon to green sectors (with possibly large regional disparities), while the total number of jobs in the economy would at best remain largely unaffected.

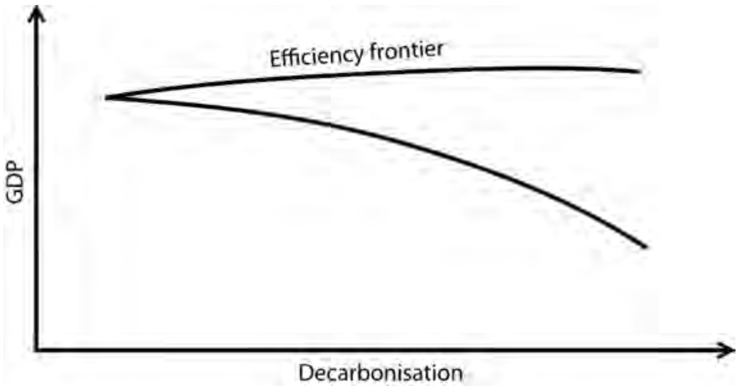
Source: OECD (2012b): Green Growth Studies: Energy.

In the first part of this chapter, it is argued that the welfare-optimal growth pattern, as calculated in various integrated assessment models, includes a substantial degree of mitigation in order to avoid the cost of climate change. However, the effects of decarbonisation on economic growth are ambiguous. To illustrate this, this section describes the different channels that link decarbonisation and economic development. In the second part, it is argued that current EU climate policies are far from the optimal frontier. Better polices allow more economic growth and faster decarbonisation at the same time. While some promising tools have been developed to stem climate change, these tools are not optimally employed. This section identifies some major impediments to the deployment of a coherent and cost-effective set of climate policies. In the third part, policy proposals that would allow the simultaneous accomplishment of more growth and faster decarbonisation are put forward.

4.2 What are the links between decarbonisation and growth?

This section discusses the links between decarbonisation and economic growth by discussing the effects of decarbonisation on economic growth, as measured by GDP. Differently put this section asks if an optimal decarbonisation policy (with respect to the level of GDP and the level of decarbonisation) can boost growth (upper line in Figure 1) or if there is a trade-off between more decarbonisation and more growth (lower line in Figure 1).

Figure 1: Can optimal decarbonisation boost growth?



Decarbonisation policies interact with economic development in a number of ways: investment and innovation are directed to low-carbon sectors and technologies; fuel imports are reduced; and, potentially, technology exports are increased. The link between decarbonisation and growth involves a set of complex interactions. This section will identify the main interactions from both a micro and macro perspective, and begins by discussing the economic effects linked to decarbonisation policies which might drive growth, *i.e.* the potentially positive links (see Table 1).

Table 1: Analysed drivers

	Long-term	Short-term
Potentially positive	• Avoided cost of climate change in the future • Double dividend • Increased innovation • International competitiveness Improved terms-of-trade • Side benefits (health, development policy)	• Demand stimulus
Potentially negative	• Cost of decarbonisation	
	• Government failure	

4.2.1 Avoided cost of future climate change

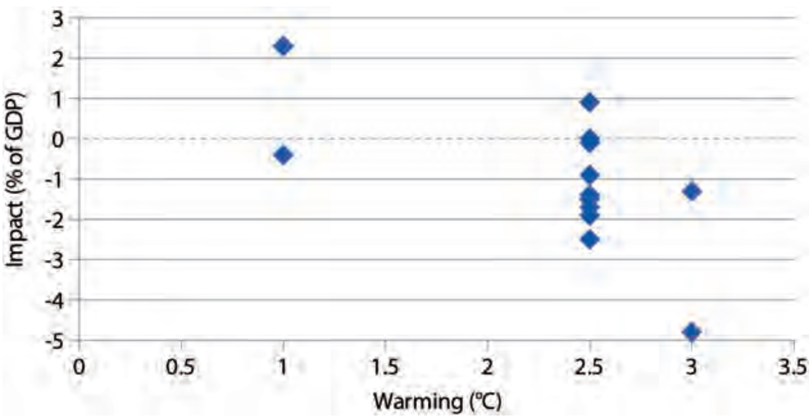
Arguably, avoided climate change costs are the major benefit of decarbonisation. Compared to a 4°C baseline, a 2°C decarbonisation scenario can imply significantly higher economic output. However, due to the ample uncertainty surrounding economic and climate models, results of different studies differ markedly. The Stern Review[62] (2007) concludes that, without action, the overall costs of climate change will be "*equivalent to an average reduction in global per-capita consumption of at least 5 percent, now and forever*". Taking into account the difficult of monetising the health and environment costs, the high responsiveness of the climate system to greenhouse-gas emissions, and the unequal distribution of effects, the total cost might be in the order of 20 percent of consumption, according to the Stern Review. Stern's figures – which imply a relatively high temperature increase of about 5°C in the baseline scenario – are at the upper end of the estimates.

Models implying a lower temperature increase calculate smaller economic effects. According to Nordhaus (2010), without decarbonisation ('uncontrolled baseline case') the global temperature would increase to 3.4 °C above 1900 levels by 2095. The corresponding damage would amount to 2.8 percent of global output in 2095.

Figure 2 illustrates the differences between 13 (meta-) studies on the impact of climate change on GDP compiled in Tol (2009).[63] Despite these differences in the numerical estimates, there is consensus that, above a certain threshold, global warming reduces welfare,[64] and that the impacts of climate change differ greatly between regions. In fact, the detrimental climate impacts of the greenhouse-effect will likely fall primarily on poorer countries. Moreover, poverty makes the populations of these countries more vulnerable – *i.e.* they are equipped with less funds for adaptation. Even within Europe the effects of climate change will vary dramatically. According to Ciscar *et al.* (2011) a 5.4 °C warming in the EU might lead to an EU annual welfare loss of -0.7 percent, but with greater losses of -1.4 percent in the south (Bulgaria, Greece, Italy, Portugal and Spain) and gains of +0.9 percent in the north (Estonia, Finland, Latvia, Lithuania and Sweden). Thus, climate change-related reductions in welfare could increase global and European inequality. Finally, it must be noted that none of the studies summarised in Figure 2 properly address extreme events. If climate change is characterised by non-linearities – that is, there are tipping points that cause irreversible and highly expensive events (*e.g.*, a shift in the gulf stream) – average damages would be an insufficient guide for policy. In conclusion, the literature unequivocally affirms that expected levels of global temperature increase will reduce global welfare.

But climate change is not an irrevocable fate. All Intergovernmental Panel on Climate Change (IPCC) reports so far assert that stabilising the concentration of greenhouse-gas emissions in the atmosphere at a reasonable level could at least mitigate climate change. In fact, all reviewed economic literature finds that policies involving a certain amount of decarbonisation increase GDP and/or welfare, because reducing emissions by a certain amount costs less than the climate-change related cost of these emissions (on the discussion about the right level of emission abatement see chapters 1 and 2). For example, Nordhaus (2010) deduces from his freely available DICE impact-assessment model that under an optimal climate policy the damages can be significantly reduced at a comparatively low decarbonisation-related cost. Correspondingly, the net present value of consumption[65] under an optimal climate policy is about 0.35 percent higher than in the baseline case. Consequently, up to a certain level, reducing carbon emissions increases GDP compared to a no-decarbonisation baseline.

Figure 2: Survey of estimates of the welfare impact of climate change (expressed as an equivalent income gain or loss in percent GDP)

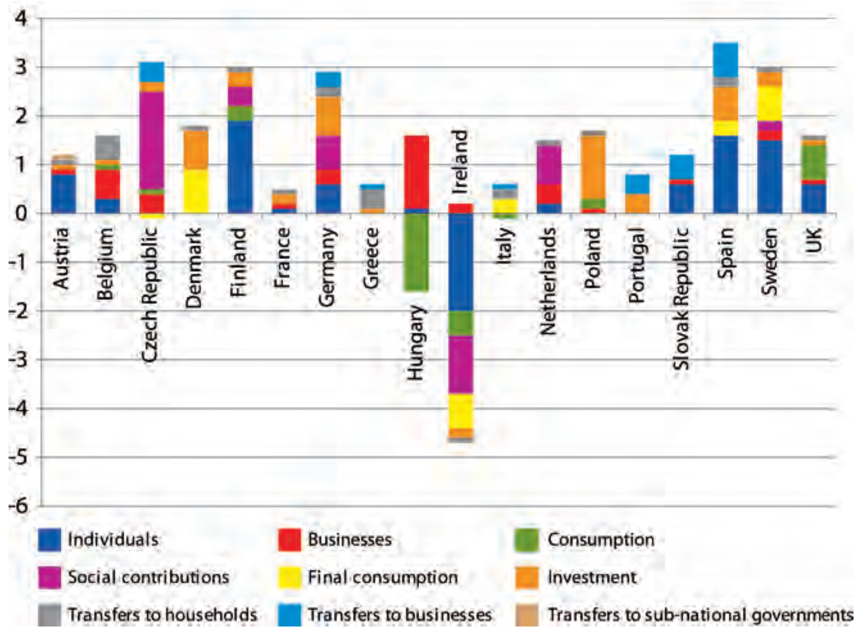


Source: Tol 2009.

4.2.2 Demand stimulus

During recessions, households and companies invest and consume less, reducing aggregate demand and output. Government spending may increase aggregate demand in such circumstances, until private actors resume investment and consumption, and help overcome the recession. The efficiency of corresponding policies is a major area of dispute in the macro-economic literature. Critics argue that discretionary stimuli largely crowd-out private spending. According to the classical Ricardian equivalence proposition, debt-financed government spending induces more savings in the private sector and hence neutralises the effect of the stimulus. Proponents of demand-stimuli have argued that this adjustment only happens in the long-term. In the short term, which is the target period for stabilising the business cycle, government spending might indeed increase

Figure 3: Size of stimuli 2008-2010 in % of GDP



Source: OECD.

aggregate demand. This is not the place to go into the detail about this long-standing macro-economic discussion on the efficiency of stimulus programmes. In practice most European countries (with the exception of Ireland) used stimulus programmes to smooth-out the effects of the crisis in 2008-2010 (see Figure 3) – and hence the design of such policies is worth being optimised.

It can be argued that stimuli that move into long-term investments have the advantage, compared to stimuli that target short-term consumption, that they improve future growth potential. Hence, a stimulus programme based on green investment might at the same time stabilise the business cycle and improve the prospects for long-term sustainable growth.

The effect of government spending depends on the change in aggregate demand generated by the increase in government spending (the multiplier effect). The multiplier might be less than one (*e.g.*, when consumers save most of the money that the government spends) or greater than one (*e.g.*, when consumers spend all of the stimulus money on goods produced domestically and the producers of those goods in turn spend the additional income on the consumption of domestic products, and so on). The efficiency of the government stimulus largely depends on the size of the multiplier. And this multiplier is known to be sector- and expenditure- specific.

It has been argued that infrastructure projects and some energy efficiency measures in buildings have particularly high multipliers, because construction workers have a high marginal propensity to consume (*i.e.*, they use most of the additional income to consume goods, which increases the aggregate demand), and construction projects have a low marginal propensity to import materials (*i.e.*, most of the intermediate goods are produced domestically).[66] Building insulation programmes, for example, typically feature significant inputs of low-skilled labour and non-tradable inputs. They are characterised by high multipliers and, hence, stimulus effects (PERI, 2011, based on input-output tables and multipliers). In addition, Helm (2011) argues that infrastructure investment is a suitable stimulus candidate, because its provision is largely driven by policy anyway. Consequently, an infrastructure-focused stimulus might increase the level of aggregate investment and hence stimulate economic activity in the short-term, while at the same time providing the infrastructure that will underpin more growth in the future. With infrastructure investment, there is only a limited risk of crowding-out private investment. The main difficulty in using infrastructure projects to stabilise business-cycles is that they involve time-consuming planning and permission procedures, and often cannot be deployed at short notice.

A number of national recovery programmes arose from the 2008 crisis that explicitly targeted green investment. While an independent and comprehensive evaluation is still outstanding, Houser (2009, pp.2-5) finds that green stimulus in the US performed as well as, or better than, traditional stimulus, creating 20 percent more jobs than traditional infrastructure spending. Also, the European Economic Recovery Plan included substantial investment in energy infrastructure, part of which is required for decarbonisation.[67]

But, the multiplier effect of government stimuli on some green investments might be less favourable. For investment in electricity generation, crowding-out is a serious issue, because public investment would largely replace private investment and thus public-debt financed generation investment has (almost) no effect on aggregated demand. The multiplier of a fiscal stimulus for promoting energy efficient behavioural change might also be very small. Hence, other sectors with potentially higher multipliers might exist. Consequently, there is some opportunity cost in channelling recovery-programme money to green investment rather than to measures promoting immediate consumption (*e.g.*, tax breaks or 'cash-for-clunkers' programmes) or to promoting other societal goals (*e.g.*, public education). In times of very limited public budgets in particular, spending on even a good programme might be bad if a better policy existed.

Furthermore, efficient policy requires that the policymaker knows the optimal level of aggregate demand in order to identify the optimal timing and volume of demand stimulus. It is not straightforward to establish this. Historic over-consumption in some countries might lead one to believe that demand expansion is warranted even when the observed contraction is structural and not cyclical. Furthermore, international free-riding on foreign fiscal stimuli limits the scope of demand stimulus policies. Finally, as the name suggests, economic stimuli are temporary measures. Hence, stimuli might be welfare-enhancing in periods of low investment and consumption by private actors, but counterproductive if conducted when economic conditions are decent.

Timing green investments to stabilise business cycles, and, hence, reach higher long-term economic growth, can be a sensible approach. However, the scope for such interventions might be limited to spending only on instruments that can be flexibly timed, are quickly deployable and have a higher multiplier effect than alternative stimulus programmes.

4.2.3 Improved terms-of-trade

Reducing energy imports might improve the terms-of-trade for energy importing countries or blocs (such as the EU). A terms-of-trade improvement implies that a country needs to sell less goods and services to foreign countries in order to be able to afford the same amount of foreign goods and services as before. The reason for this effect is that, at a given supply, reducing energy demand reduces the world market price of fossil fuels. This effect might be amplified by the 'green paradox' (Sinn, 2008) and the market power of fossil-fuel exporters. The green paradox presumes that oil producers who expect tighter climate policies in the future react by producing more oil today, thereby reducing oil prices. Meanwhile, the market power of fossil-fuel exporters might make prices more reactive to changes in demand. When demand is high, certain exporters become pivotal and can then include a significant mark-up in their prices. If demand is reduced below a certain point, the marginal cost of fuel production declines (*i.e.*, the most expensive price-setting oil fields are not needed any more) but the mark-up will also shrink (*e.g.*, OPEC producers start mutually competing for market share) and, hence, fuel prices drop more than proportionally. The terms-of-trade of energy importers improve because of reduced fuel prices. Specifically, EU countries will have to export less in order to pay for foreign fuels. Due to the lower spending on fuel imports, domestic consumption and consumer welfare can increase. However, this price effect on the European economy might be relatively small. Lower fuel prices not only have a positive effect on the countries that reduce their fuel consumption, but also have a positive effect on all other energy-importing economies. Hence, a European reduction in fuel imports might eventually dampen the energy import cost of its main competitors. When combined with carbon-price induced high energy costs in Europe, the lower energy import costs of other countries might lead to a shift of polluting activities from Europe to non-European countries ('indirect leakage').[68]

Beyond the (potentially small) terms-of-trade improvement related to reductions in imports of fossil fuels, there is a vivid discussion in the literature about the effect of energy imports on the macro economy. Most of the literature is concerned with the economic impact (inflation, GDP) of oil prices on importing countries.[69] Economic literature has identified various channels that link oil prices to GDP.[70] Some consensus has emerged that historic data indicate a negative effect of high oil prices on growth, and that this link is somewhat less for developed economies because their energy intensity (energy consumption divided by GDP) is decreasing, their labour markets are becoming more flexible and their monetary policymakers have learned how to accommodate oil price shocks.

The finding that oil price shocks have some impact on GDP is sometimes used by decarbonisation advocates to (implicitly) claim that energy-import reductions resulting from decarbonisation might be economically beneficial for energy-importing countries.

But beyond the terms-of-trade effect, the effect on GDP of replacing expensive fossil-fuel imports with more expensive domestic energy (or energy-saving investments) is likely to be negative. Lower volumes of imports translate into lower fuel import bills. For example, the billions of euros saved because of avoided energy inputs feature as headline figures in the impact assessment of the European Commission's proposal to move beyond the 20 percent decarbonisation target by 2020[71] (savings of €9.1 billion for moving to a 25 percent target and €14.1 billion for moving to a 30 percent target[72]). However, the substitution of imports with investments in new energy technologies, and with demand reductions, is not *per se* growth enhancing. Continuing to consume imported fuels relatively cheaply and investing the savings in production with higher added-value than investment in substituting energy imports, would result in higher GDP. Additionally, the argument that the finite nature of fossil fuels calls for a change in resource intensity does not strictly imply that policies that reduce fuel imports are welfare enhancing, because the optimal speed of change in resource intensity might be driven by fuel prices alone.

4.2.4 Double dividend

Pigovian taxes on pollution and systems of tradable emission allowances are key instruments for decarbonisation. These instruments can generate substantial public income. For example, the value of annually issued EU emission allowances[73] is in the range of €20-40 billion. These revenues might be used to reduce distorting taxes on labour and capital. There is an extensive literature discussing whether a corresponding shift in the tax structure might lead to a '**double dividend**' (see Goulder, 1995, and Schöb, 2003). This literature discusses if replacing taxes on labour and capital with green taxes might generate growth.

From a fiscal point of view, green taxes are not *per se* preferable to other taxes, as they are typically regressive, make industry less competitive, and, when effective, kill their own tax basis (Bénassy-Quéré *et al.*, 2010, p.607). However, in countries with inefficient tax regimes, a tax reform might lead to higher economic growth. Depending on the pre-existing tax structure, such an efficiency-enhancing tax reform could feature some green taxes. Thus, if green taxes are solely used to replace the most distorting taxes in an existing tax system, they might indeed be growth-friendly.[74]

Additionally, taxes on mainly imported goods can increase the welfare of a country by improving its terms-of-trade. The idea is that if a tax restricts demand, foreign exporters might want to reduce sales prices to keep sales up in order to maximise their income (see Bickerdike, 1906). Hence, taxing forms of mainly imported energy which are currently not taxed (*e.g.*, kerosene) might increase the welfare of all importing countries while reducing pollution.

4.2.5 Increased innovation

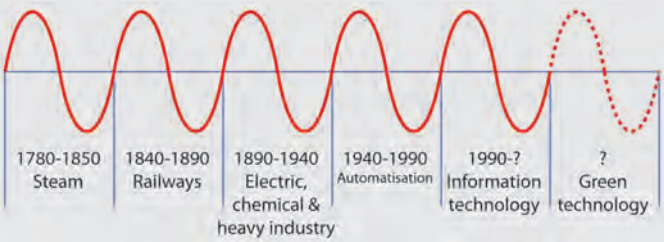
One often-advanced argument for green growth is that decarbonisation policies encourage and incentivise firms and individuals to engage in rapid technological innovation and diffusion, enabling faster economic growth and development. It has even been argued that green breakthrough technologies might give rise to a new economic cycle (see Box 2). Several studies posit that innovation contributes significantly to sustainable growth and productivity enhancements in the long-run.

Box 2: A sixth Kondratieff?

In public debates, proponents of the view that decarbonisation could be a source of growth sometimes refer to the concept of Kondratieff waves. Kondratieff in the 1920s postulated that long-term economic developments are characterised by long waves of 40-60 year lengths, which can be attributed to the introduction, maturity and saturation of key technologies. The advocates of this theory identify five major canonical waves: the steam engine (circa 1780-1850), railways (circa 1840-1890), electricity, chemicals and heavy industry (1890-1940), automatisation (circa 1940-1990), and information technology (circa 1990-). It is argued that there might be a sixth Kondratieff wave based on green technologies. Hence, the decarbonisation imperative might give rise to a new economy that would drive growth in coming decades.

The concept is difficult to refute as it has not been laid out in rigorous scientific form. Hence, the main criticism is criticism of the Kondratieff concept overall. The postulated long waves are not clearly identifiable in the data, and the attribution of them to technologies is ambiguous. In addition, green technologies so far do not seem to satisfy new needs but rather replace cheap and versatile energy (*e.g.*, oil) with cleaner alternatives. Thus, in contrast to past 'enabling' technology developments, green technologies will substitute for high-carbon technologies based on decarbonisation policies, not on consumer preferences. Finally, it is not clear what policy recommendations might stem from the possibility of an eventual sixth Kondratieff wave, based on green technology, because past cycles have developed in very different economic policy environments.

Figure 4: Stylised representation of Kondratieff cycles



There are two key lines of argument that seek to explain why decarbonisation might boost innovation and, hence, growth.

The first argument is commonly referred to as the '**Porter Hypothesis**'. Porter and van der Linde (1995) argue that the inevitable struggle between environmentally-friendly policy and economic growth should not be approached from a static perspective. Rather, stringent regulation might pay for itself by inducing private-sector innovation in the medium- and long runs. This argument appears counter-intuitive, as regulation imposes costs on companies and reduces their ability to compete with non-regulated companies (*e.g.*, in international markets). According to the Porter Hypothesis, because of a number of imperfections, companies pursuing business-as-usual might ignore profit opportunities. Environmental regulation might therefore cause companies to adopt more innovative business models, or improve their products or production processes. The Porter Hypothesis is supported by the conjecture that entrepreneurs might be risk-averse (Kennedy, 1994), and try to avoid costly change (Aghion *et al.*, 1997; Ambec and Barla, 2002, 2007). In addition, the existence of bounded rationality in managers – their inability to consider all the potential benefits a costly green innovation might have – might support Porter and van der Linde's premise. Either way, according to this hypothesis, stringent regulation and its subsequent entrepreneurial stimulus leads to more regulated economies becoming more competitive. Competitiveness leads, finally, to sustainable growth and welfare. The Porter Hypothesis can be segmented into two parts which can be examined empirically. First, it assumes that regulated companies innovate more, and second, that this increased innovation improves the competitiveness of the regulated companies. Empirical evidence on the Porter Hypothesis is mixed.

The literature largely backs the first part of the hypothesis. Jaffe and Palmer (1997) find a positive relationship between pollution abatement cost, and total R&D expenditure and numbers of successful patent applications. Pollution abatement costs can be interpreted as arising from environmental regulations. Brunnermeier and Cohen (2003) report a positive impact of environmental regulation on environmentally-related successful patents in the US. This is also reported by Popp (2006) for German and Japanese data. Arimura *et al.* (2007) and Johnstone and Labonne (2006) test the effect of environmental regulation stringency on the probability of investment in green R&D. Both studies find a slightly positive relationship.

Evidence for the claim that innovation incentivised by regulation improves the competitiveness of companies is less clear. Studies reviewed by Jaffe *et al.* (1995) mostly show a negative effect of environmental regulation on net exports, trade in pollution-intensive goods, foreign direct investment, domestic plant location and total factor productivity. Kalt (1988), using US manufacturing data from 1967-77, estimated a significant negative impact of compliance costs on net exports. These studies incorporate an elementary caveat – it is debatable if roughly aggregated data is able to show the impact of single policy regulations when, in an open economy, the performance and productivity of firms depend on several factors. More recent studies used detailed firm-level data in specific sectors to test the Porter Hypothesis. Berman and Bui (2001) report that refineries located in Los Angeles are significantly more productive than other US refineries despite more stringent air pollution regulation in California. However, Darnall *et al.* (2007) show that increased innovation does not necessarily mean that firm performance will increase. This is partly supported Lanoie *et al.* (2008), who find that the positive effect of innovation on business performance does not outweigh the negative effect of the regulation itself. Consequently, the literature seems to suggest that environmental regulation indeed increases the level of innovation in the affected companies, while the effect on their overall economic performance appears ambiguous.

The second argument for why decarbonisation-related innovation might boost growth comes from the macroeconomic idea **that increased investments in innovation lead to higher future growth**. The importance of technological change for long-term growth is described in endogenous growth models. In these models, innovation is the driving force of sustainable economic development. Endogenous growth models rely on the assumption that greater R&D expenditure leads to more growth which allows for additional R&D investments, accelerating economic development (Aghion and Howitt, 1992).[75] As the level of innovation investment is deemed insufficient in Europe – Europe misses its famous innovation spending equal to 3 percent of GDP target by a long shot – more innovation investment could boost growth. It could be argued that decarbonisation policies that stimulate green innovation facilitate growth.

Two types of decarbonisation policy have been widely used to stimulate innovation. Push policies attempt to directly increase the level of innovation by providing R&D subsidies or conducting public R&D. Pull policies attempt to generate a market for new low-carbon technologies through regulation, emissions trading or public procurement of technologies. The literature suggests that, depending on the technology and its maturity, it would be most effective to employ a situation-specific combination of both approaches. For example, OECD (2011) indicates that, for hybrid vehicles, public R&D spending is more effective than emission standards, while for battery electric vehicles, tightening emission standards has a stronger effect on patenting activity.

The OECD study and other studies also counter the argument that all public R&D support policies crowd-out private R&D investment. The potential replacement of firm-financed R&D by government-sponsored research (crowding-out) would prevent government R&D policies from being effective. Empirical evidence for crowding-out typically finds that government spending-induced reductions in private R&D spending do not outweigh the initial effect (Czarnitzki and Hussinger, 2004; Busom, 2000; Wallsten, 2000). Any R&D subsidy can be seen as lowering the private cost of a project. Receiving the subsidy for green innovation may therefore turn an unprofitable project, *i.e.* investment in green technology, into a profitable one to be pursued by the firm. It may also accelerate the completion of an otherwise under-financed project. Furthermore, if the R&D subsidy is used to improve or upgrade research facilities, then the fixed cost of parallel or future projects is reduced, increasing the probability of additional investment by the firm (Lach, 2002). The learning, and more rapidly obtained results from subsidised projects, can also generate spill-overs to non-subsidised green innovation projects. Spillovers could incentivise firms to focus more on green projects instead of the undesired dirty technology. Additionally, government R&D subsidies can provide a positive signal for private investors, promoting socially desired research (Kleer, 2010). The same holds true for public R&D. Popp (2006) examined citations referring to energy technology patents, and found that privately-held patents that cited government patents became in turn the most frequently cited, suggesting a fruitful transfer of government research results to private industry.

It is self-evident that effective incentives for green innovation lead to more green R&D. From a growth perspective, however, the question is if the benefits exceed the costs of innovation-enhancing decarbonisation policies (this includes the opportunity cost of spending the money on other projects). In particular, there is a question why focusing on green innovation would be more growth friendly than more general innovation policies. Acemoglu *et al.* (2012) explain that there is private under-investment in green innovation even when it is better than high-carbon innovation from a long-term growth perspective. The main goals of supporting green innovation are (a) to increase the share of green R&D in total R&D and (b) to increase total R&D intensity, in order to generate growth, subject to the fulfilment of the first objective. High-carbon technologies are characterised by polluting production methods and reliance on limited natural resources. At some point, their growth will be restrained by natural factors. Green technologies such as the transformation of renewable energy sources into usable energy, on the other hand, have virtually infinite growth potential. Consequently, switching to new technologies earlier is welfare enhancing, since the size of the green sectors and green innovation will grow endogenously because of learning-by-doing, economies of scale within companies and positive spill-over effects between companies. Green innovation in turn allows the green sector to grow faster. This endogenous relationship between innovation, productivity enhancements and production is a key to long-term growth.

By changing the relative size of green and high-carbon innovation activities, innovation policy would also change the contribution of the two sectors to growth. If the green sector is sufficiently large, standing-on-the-shoulders-of-giants feedbacks would be enjoyed by the sector, and would foster innovation. Therefore, decarbonisation policies that directly or indirectly support green innovation might allow countries to move to a higher growth path (at the price of lower short-term growth).

4.2.6 International competitiveness

Beyond global economic effects, decarbonisation might also improve the competitive position of individual economies. Redirecting innovation and investment, at an early stage, to the growing clean technology sectors might help some countries retain or even strengthen their **international competitiveness.** This could boost their economies and create jobs. Huberty and Zachmann (2011) argue that state-supported deployment can partly explain the export success of the Danish and German wind industry.

However, the question is whether the cost of supporting the expansion of a green industry that is expected to have higher growth potential will actually be compensated for by later gains. This boils down to the question of why private companies alone do not focus on the most attractive sector. One argument is that green industries form clusters. While early-movers incur high costs in establishing the clusters, the positive spillovers provided by the early-mover (education of workers in the new field, the creation of an infrastructure of suppliers, etc.) can be reaped for free by second-movers. Hence, government intervention to overcome reluctance to bear first-mover costs might be justified under two conditions: the country has an initial advantage in the new sector, and the new sector promises to pay back the initial cost through later (tax) revenues. However, operationalising these conditions is difficult, and, hence, the decision on the sectors to support is prone to costly government failure. Supporting the wrong technologies may lead to loss of valuable time and/or costly lock-in.

Nevertheless, the principle of supporting new green technologies – essentially, green industrial policy – has attracted massive interest throughout worldwide.[76] In 2011, German future support commitments to renewable electricity generation had a net present value of approximately €100 billion.[77] China has also engaged heavily in renewable energy technologies by enacting long-term production tax credits (wind) and investment tax credits (solar), while in the US tax credits have been used to encourage the deployment of wind power generation.

Domestic companies can also be made more competitive on the world market through environmental standards that protect domestic industry. In a situation of imperfect inter-firm competition, Simpson and Bradford (1996) show that a government may provide a strategic advantage to its domestic industry by imposing more stringent environmental regulation. For example, vehicle-fleet emission standards might increase the competitiveness of domestic companies that could invest in more developed technologies (that meet the standards), at the expense of domestic customers that are not allowed to buy less-efficient products. While such policies appear efficient from a single-country perspective, when considering potential retaliation (*e.g.* other countries implementing different standards), corresponding green trade barriers can quickly become detrimental to international trade and, hence, growth.

4.2.7 Side-benefits

Decarbonising the economy might produce a number of side-benefits that indirectly increase GDP but are not necessarily incorporated in economic models, because it is difficult to quantify these benefits.

One potential side-benefit is that **decarbonisation might act as a development policy**. Albeit less relevant for the EU, it has been claimed that decarbonisation might have positive spillovers for economic growth in developing countries. The development of decentralised renewable electricity sources might make rural electrification cheaper in developing countries. Some developing countries have a comparative advantage in producing alternative energies (biofuels, solar power), and decarbonisation measures in developed countries might have growth-enhancing effects in developing countries.

Reducing the combustion of fossil fuels would reduce the **impact of pollution on public health**. Pollution from the combustion of fossil fuels negatively affects economic growth because it incurs public health costs, and results in lost labour productivity and lost land productivity. In 2005, the cost of pollution was an estimated 3.8 percent of China's GDP (World Bank, 2007). In the US, the health costs resulting from air pollution amount to approximately $120 billion a year (US National Research Council, 2009). The figure takes into account health impacts from electricity generation and transport, but does not include health costs resulting from the effects of some air pollutants, climate change or damage to ecosystems.

Hence, decarbonising the economy by reducing the combustion of fossil fuels in power and heat production and by transport, might imply significant public health improvements.

4.2.8 Avoiding carbon is costly

We now turn to the drivers that imply a potentially negative relationship between decarbonisation and economic growth. Decarbonisation comes at a cost. If an economy is at equilibrium, imposing green regulations and taxes *ceteris paribus* reduces GDP. Including the cost of carbon in product prices causes them to be consumed less, and, hence, decreases production.

Furthermore, the inclusion of the cost of carbon might make some products less competitive on the international market, thereby reducing domestic added value in the respective sectors. Parts of the existing stock of physical capital, human capital and knowledge complementary to high-carbon technologies are devalued by green regulation (Smulders and Withagen, 2011). For example, existing lignite power plants might become uncompetitive due to high carbon prices. The specific skills acquired by employees of lignite mines and power plants would then become less valued by the market. Patents related to lignite power plants would also lose value.

According to Smulders (2005), both the positive and negative effects of decarbonisation on growth are amplified if one assumes endogenous technical change. Reduced activity in the high-carbon sector would mean that less innovation would take place in related industries. However, increased activity in the low-carbon sector would increase innovation there. Assuming that both sectors' innovative activities are equally responsive to the respective outputs in the sectors, a net reduction in output would lead to a reduction in overall innovation and, therefore, growth potential. That is, if companies produce less in a country, they also invest less in R&D. Lower R&D investments subsequently reduce future production.

According to some recent models, the speed at which emissions are reduced, combined with the level of reduction, may play a determining role in the total economic cost of decarbonisation (Edenhofer *et al.*, 2009, 2010; and Clarke *et al.*, 2009). Without taking climate change externalities into account, these models estimate that reductions of about 0.5 percent, 1-2 percent, and 2-7 percent respectively in global GDP would result from reductions of emissions to 650 parts per million carbon dioxide equivalent (CO_2eq)[78], 550 ppm CO_2eq, and 450 ppm CO_2eq. Another study (Tavoni and Tol, 2010) estimates the economic loss to be higher, as much as 8-13 percent of global GDP, in the 450 ppm CO_2eq scenario. However, if carbon capture, or some other backstop CO_2-removal technology, is included for fossil fuel-burning plants, the model average cost for the 450 ppm scenario is reduced to 2-2.5 percent of global GDP. This means that technology assumptions are critical to cost estimation. The Stern Review estimated adjustment costs for the 550 ppm scenario to be around 1 percent, on average, and identified a range of 1-3.5 percent of GDP (Stern, 2007). The OECD Environmental Outlook to 2050 estimates that a reduction of GDP in 2050 of 5.5 percent would result from a cost-effective pathway to the 450 ppm scenario.[79]

4.2.9 Policy failures

Many of the arguments for green growth are based on the assumption that present inefficient government and private actions will be corrected by an optimal green policy. If green taxes replace the most distorting taxes, if regulations encourage companies to take profitable energy-efficiency measures that they did not consider before, if decarbonisation policies increase innovation, and if governments use green stimuli only in sectors with high multipliers and during times of depressed aggregate demand, there is ample room for green growth.

However, it is unlikely, that the quality of economic policy decisions will improve only because the policies are now green. In fact, decarbonisation requires significant policy intervention. Consequently, policy failures could have more severe consequences than in a no-decarbonisation scenario. According to Helm (2011), decarbonisation policies are prone to "*government failure, rent capture and lobbying*". National decarbonisation policies might reduce international trade, pick the wrong technologies and waste public money. Helm (2011) argues that EU policies provide evidence that "*the most expensive options are chosen first*".

Box 3: War against climate change

Many of the arguments that could justify green growth might have been employed equally well in support of one of the oldest and most sizable government policies: military expenditure. Military expenditure has been linked to many productivity-improving civil innovations, such as civil aviation or the internet. Large-scale military spending has been used to stabilise business cycles, replace cheap energy imports with expensive domestic energy sources (coal liquefaction), and to create a competitive edge when exporting military equipment. Even improved healthcare has been linked with military expenditure (Benoit, 1978). The ultimate aim of both green and military expenditure policies has been, in many countries, to insure against 'disaster'.

Surprisingly, the literature does not provide a comprehensive answer to the question of whether, and under what conditions, military expenditure is growth friendly. Several authors have found correlations between military spending and growth. Landau (1996) finds that, below a certain threshold, increased military expenditure is growth enhancing. However, other authors either claim that these correlations do not constitute causality or do not find a correlation at all (Benoit, 1978, for developed countries). Some even detect negative correlation – Faini *et al*. (1984) find on average a 0.13 percent lower GDP growth rate for each 10 percent of increase in military expenditure. They present some negative spin-off effects which associate higher military burdens with higher taxation, shifts from agriculture to manufacturing, and lower saving/investment shares. Smith (1980) also found that military expenditure had a negative impact on investment in 13 OECD countries. An interesting natural experiment in this context is the alleged peace dividend after the end of the Cold War.

Hence, despite major military investment and innovation efforts, there is no clearly attributable effect of military expenditure on economic growth. The inconclusiveness of the literature on the growth impact of military spending serves as a reminder of how difficult it might be to properly identify the presence/absence of green growth.

4.2.10 Summary

Mitigating carbon emissions increases welfare compared to business-as-usual and acts as insurance against catastrophic events. On whether decarbonisation will lead to higher GDP in Europe compared to business-as-usual, the literature is inconclusive (see Box 3 for a consideration of a comparable area). Even proponents of increased mitigation find that "*the direct effect of the decarbonised pathways on overall GDP growth is negligible*" (ECF Energy Roadmap, 2010).

In addition to the direct economic costs and benefits of emission mitigation, decarbonisation might drive economic growth in other ways. Decarbonisation policies can be growth friendly if they resolve existing government or market failures that impede growth. Potential opportunities for green policies to reduce growth barriers include: cyclical unemployment, growth unfriendly tax structures, unfavourable terms-of-trade, insufficient innovation, insufficient aggregate investment and inadequate development policy. The cumulative interaction of these effects is difficult to establish – in particular, because the net effect depends on the implementation of decarbonisation policies.

Overall, there is limited evidence for decarbonisation as a tool for generating additional growth. In fact, the current economic crisis confirms that reducing output is still the most straightforward way to curb carbon emissions. Given what we know today, the clearest motivation for decarbonisation is that it is a necessary insurance against potentially catastrophic events, and a tool for containing global inequality.

4.3 What is the growth impact of current climate policy?

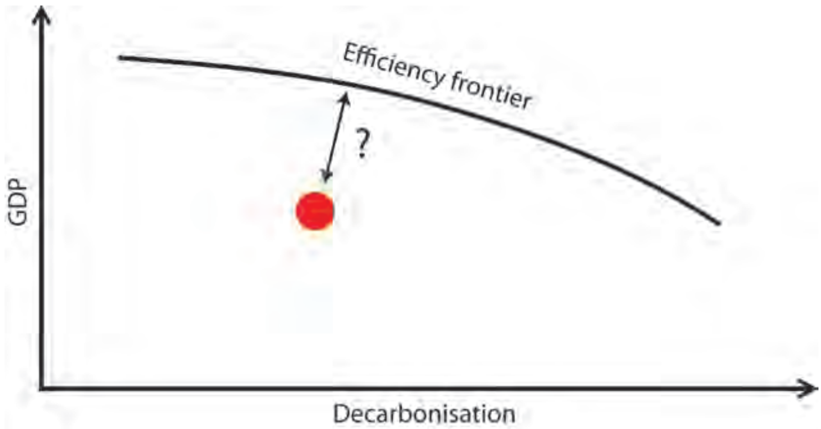
The previous section explained that decarbonisation policies that resolve existing government or market failures might be growth friendly, while there is a risk that inefficient decarbonisation policies may be detrimental to growth. Hence, whether decarbonisation can, in total, generate additional growth or not, policymakers should strive to reduce the cost of decarbonisation, while increasing the potential benefits of decarbonisation. In the past decade, the EU and its member states have already implemented a number of decarbonisation policies. This section aims to determine to what extent European climate policy is able to reconcile its decarbonisation objective with its long-term growth objective.

Put differently, while the previous section asked what the trade-off is between decarbonisation and growth, this section asks how far current European climate policy is from the efficiency frontier (see Figure 5).

4.3.1 Some unprecedented tools

European decarbonisation policies are motivated by a mid-term strategy and a long-term strategy. The mid-term strategy, commonly referred to as the 20-

Figure 5: How far are we from the efficiency frontier?



20-20 targets, foresees the reduction of greenhouse gas emissions by 20 percent compared to 1990, an increase in energy efficiency by 20 percent and the achievement of a share of 20 percent of renewable sources in the fuel mix by 2020. The long-term target is a reduction of greenhouse-gas emissions by 80-95 percent by 2050.

In order to achieve its decarbonisation targets, the EU has developed some (at this scale) unprecedented tools. The European Emission Trading System (ETS), for example, induces emissions reductions by the installations that have the lowest mitigation cost and without much institutional overhead throughout Europe. The reduction of about 180,000 tonnes of annual CO_2 emissions between 2005 and 2010 in the sectors covered by the ETS can be partly attributed to this mechanism (the other part of the reductions is due to the economic crisis that led to a reduction in polluting activities). This reduction in emissions was not accompanied by significant reductions in the profits of companies covered by the ETS, even though the share of free allocation of allowances was reduced for some sectors.[80]

Furthermore, support for the deployment of renewable energy sources has helped to reduce the unit cost of some massively deployed low-carbon technologies. The price of solar panels, for example, fell from about $5 per watt of installed power in 2000 to about $2 per watt in 2010.[81] In addition, massive domestic deployment of renewables has given some countries a competitive edge in these technologies. For example, Denmark and Germany were able to develop globally competitive wind-turbine industries.[82]

Moreover, support for decarbonisation related R&D has been substantial. About one fifth (about €11 billion) of the current European seven-year research budget (2007-13) has been allocated to energy, environment, transport and nuclear research, and hence, to fields that are largely related to low-carbon technologies. In addition, member states have committed substantial resources for research and development of low-carbon technologies.[83] This support helped Europe to become a leader in clean technology innovation. In 2010, Europe was responsible for 32 percent of global clean-energy technology patents.[84]

Europe's policies have so far been effective in terms of the EU's mid-term decarbonisation targets (-20 percent by 2020). But, for a number of reasons, their cost effectiveness (*i.e.*, efficiency) and their ability to achieve the long term targets (-80-95 percent by 2050) have been called into question. Current policies are deviating from an optimal growth pattern and hence European decarbonisation policies might become detrimental to economic growth. The following section discusses six key inefficiencies.

4.3.2 Lack of a global approach

At the end of 2012, the first commitment period of the Kyoto protocol, in which 37 of the 191 participating countries committed to collectively reduce greenhouse-gas emissions by 4.2 percent between 1990 and 2012, will expire. So far, the establishment of a legally binding second commitment period up to 2020 has failed.[85] Currently, 141 countries representing 87 percent of current emissions have made non-legally binding pledges for emissions targets to be achieved by 2020. Emerging countries have pledged to contain the growth of their emissions, while most industrialised countries have signaled their willingness to reduce annual emissions. In total, the pledges for 2020 amount to an increase in global emissions of about 18 percent compared to 1990.[86] This approach will not deliver low-cost decarbonisation for four reasons. First, the pledges are insufficient. An 18 percent increase in emissions is "*not ambitious enough to put us on a pathway* *to limit average global temperature rise to 2°C".*[87] Second, the pledges are only made with respect to 2020 and, hence, fail to provide the stable long-term perspective critical for incentivising investment. Third, the pledges are non-binding, so countries might fall short of their decarbonisation targets without sanction, and thus will be reluctant to make any costly decarbonisation decisions – in particular, if they see that other countries are not living up to their pledges either. Fourth, it is unlikely that the pledges will be distributed among countries in a cost-optimal fashion. Due to the lack of binding targets, countries cannot trade emission rights to achieve an ex post optimal allocation of mitigation targets.

Hence, the absence of a binding global approach creates significant inefficiencies. According to results by Hübler *et al.* (2012), global international action with international emissions trading would be significantly cheaper for Europe and more efficient globally than the current fragmented policy. Optimal global international action would lead to a lower emissions reduction in the EU (60 percent in the optimal path instead of the current ambition of at least 80 percent by 2050) and thus much lower mitigation costs (a 0.5 percent decrease in consumption under the optimal path, as opposed to a 1.5 percent decrease in the business-as-usual scenario).

Without an international consensus, decarbonisation will be much more expensive at the global scale. Expensive mitigation action by a large group of countries can be undone relatively easily by countries that want to fuel their short-term economic development with comparatively cheap fossil fuels.

Consequently, in the absence of a global agreement, a long-term continuation of European unilateral action will lead the EU to forgo significant economic growth potential.

4.3.3 Short-termism of EU policies

According to the EU Energy Roadmap 2050 impact assessment, investments of about €1 trillion per year up to 2050 are necessary in the energy sector.[88] Thus, long-term investment signals are critical to the decarbonisation of the energy system. However, there is no comprehensive European policy framework in place to achieve the EU greenhouse gas emission reduction of

80-95 percent by 2050 compared to 1990. The main political reason is that the EU strives to reserve some space to adapt its climate policy in the context of varying possible outcomes of international climate negotiations. As chapter 2 argues, this deliberate ambiguity exists for a sound economic reason. However, it is the source of political uncertainty for the long-term decarbonisation pathway within Europe.

So far, only the EU ETS, which has no legally binding sunset clause, provides a decarbonisation anchor. The number of emission allowances issued under the ETS is supposed to be reduced each year by about 1.74 percent of the average annual level of the Phase II (2008-12) cap. The reduction in allowances would imply that, from about 2070 on, no more new emission allowances will be issued. However, the ETS currently only covers about half of EU greenhouse gas emissions. Emissions from transport or domestic heating are exempt from the competition for a decreasing supply of allowances. Furthermore, the linear reduction factor is less binding than the concept suggests. Current discussions about a set-aside of emission allowances in order to stabilise the allowance price are a telling example of the lack of time-consistency in the ETS. The possibility to import allowances into the system by transforming emission reduction certificates from other countries[89] or exchanging allowances with other emission trading systems also gives future policy-makers some discretion over the volume of allowances in the ETS. Furthermore, the political discussion about the 2020 and the 2030 decarbonisation targets suggests that there is only limited belief in the linear decarbonisation trajectory.

The uncertainty over the future tightness of the ETS has reduced it to an effective short-term tool. Current prices mainly reflect current demand and supply of allowances but do not signal potential future scarcity.[90] It is difficult for investors to base the necessary long-term investment decisions on current European climate policy. Thus, private actors will prefer to delay investments and invest in less capital-intensive assets, and the capital-intensive low-carbon investments (*e.g.*, zero-carbon power plants) required for low-cost decarbonisation will not be provided by the market. Corresponding delays will compromise growth already in the near term. More importantly, current investment in high carbon-intensive assets will leave the EU with the future choice of either delaying decarbonisation or sacrificing consumption to replace existing assets that have not reached the end of their economic lifetime. Consequently, the lack of a long-term framework is stopping decarbonisation from being efficiently accommodated within current and future growth.

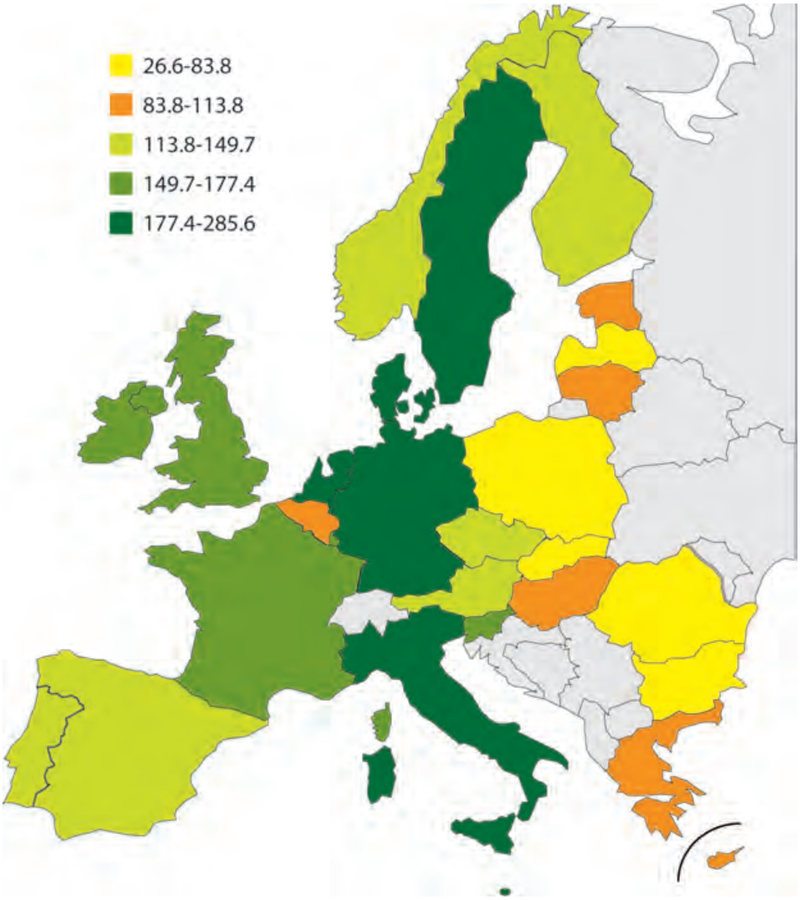
4.3.4 Different carbon prices in different sectors

Not only do carbon prices not reflect long-term scarcity, but there exist multiple carbon prices – *i.e.* different sectors face different marginal abatement costs.[91] Böhringer *et al.* (2009) theoretically and analytically show that having different (implicit) prices for carbon in different sectors results in a welfare loss. The segmentation of European decarbonisation into sectors that are covered by the ETS and sectors that are not covered, results in potentially significant excess costs. The inefficiencies are aggravated by the absence of a benchmark value for carbon mitigation in the non-ETS sectors. In the non-ETS sectors a mixture of command-and-control instruments and taxes is used to drive mitigation. The policies vary widely in the different sub-sectors. Inefficiencies accrue if abatement is encouraged/enforced in sub-sectors with very high abatement costs (such as biofuels[92]), while some lower cost abatement options (such as insulation) remain unused. The modeling results in Böhringer *et al.* suggest that inefficiencies in policy could lead to costs that are 100-125 percent higher than necessary. Hence, the current policy of differing carbon prices in different sectors is reducing the EU's growth potential.

4.3.5 Different carbon prices in different countries

Tol (2011) adds that, because of national regulations, there are at least 28 prices for carbon – *"one in the ETS and at least one per member state for non-ETS emissions".* Consequently, explicit and implicit carbon prices differ between sectors and countries. A striking example is the different national approaches towards the final price of energy for households (heating, transport). Fossil-fuel consumption for heating and individual transport is a major source of non-ETS carbon emissions. The price of fossil fuels for heating and transport is largely determined politically through regulation and taxation. But as energy taxes vary widely between EU countries (see Figure 6), the final price for energy differs between countries. Consequently, the incentives for reducing energy consumption are very different across European countries. If some of the energy saving investments we see in the high energy-cost

Figure 6: Implicit tax rate on energy (2009)



Source: Eurostat (Ratio of energy tax revenues to final energy consumption, deflated).

countries would instead be done in the low energy-cost countries, this could reduce emissions at lower cost.

National regulation is another issue. While in some countries (for example France), household consumers obtain electricity at below-cost prices because retail tariffs are regulated, electricity consumption in other countries (for example Germany) is made comparatively expensive by concession levies, energy and value added taxes, renewable energy apportionment, regulated network tariffs and other publicly determined cost components. This different treatment of final electricity consumption has noticeable effects. French consumers heat more often with inefficient electric heating systems and have less well insulated houses than Germans.[93] Consequently, French households on average in 2010 consumed 2,511 kilowatt hours (kWh) per person compared to 1,732 kWh in Germany and 1,682 kWh in the EU27.[94] This indicates a certain level of energy wastage in France that requires more expensive mitigation action elsewhere if Europe wants to achieve its climate targets. Higher levels of growth could be achieved in Europe if national differentiation in energy prices could be overcome.

In addition, national carbon policies may also overlap with EU-level policies, increasing the cost of emission reduction for the EU as a whole. For example, the proposed United Kingdom carbon floor price would increase the price of carbon within the UK. If the UK floor price is above the ETS price, industry in the UK would have an incentive to reduce emissions beyond the level stipulated by the ETS price, or to shift emissions to other member states not subject to the floor price, leading to increased imports of carbon-intensive products and services into the UK. This would not change the EU's overall emissions because there is an overall cap, but it would increase the cost of meeting the target. National carbon regulations on top of European regulations are thus detrimental to the European economy.

4.3.6 Overlapping policies

Overlapping policies, even if they have the same objective to reduce emissions, might interact to reduce each others' effectiveness, resulting in unwanted side-effects and ultimately reducing growth (see Box 4). Böhringer and Rosendahl (2010) demonstrated theoretically that the imposition of renewables quotas on top of an emissions cap increases the cost of emissions reductions, and boosts the performance of the most carbon-intensive mode of electricity production (lignite power production), relative to an emission cap alone. They quantified this with simulated policy scenarios, using data from the German electricity market. The analysis indicates that renewables policies that overlap with emission policies decrease the price of emissions allowances, because fewer allowances are required because of increased renewables generation. This ultimately benefits the most emission-intensive technologies. First sketchy empirical evidence of this 'green serves the dirtiest' phenomenon can be found in the development of the German fuel mix. While between 2008 and 2011 Germany's share of renewables was pushed up from 14.5 percent to 19.9 percent by the German feed-in tariffs, the share of hard coal decreased. At the same time, the share of lignite – the most carbon-intensive generation technology – increased.[95]

Box 4: Interaction of cap and trade and subsidies for low-carbon investment

This Box provides a stylised presentation of the economics that shape the interaction between cap-and-trade and subsidies in favour of low-carbon investment that cap-and-trade intends to encourage. The most obvious example is support for renewable electricity. The arguments that follow also apply to support in favour of energy efficiency that is governed by cap-and-trade.

Supply of and demand for carbon emission permits

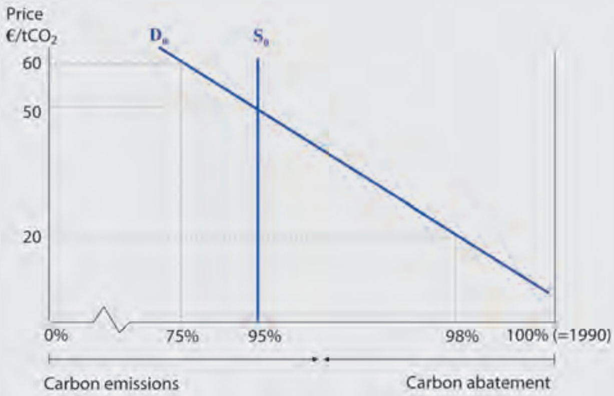
In diagram 1, the vertical curve S_0 pictures the fixed supply of emission permits: that is, the supply of permits does not depend on the carbon price, which is measured by the vertical axis. Note the horizontal axis can be understood in two ways. First, reading it from left to right indicates carbon emissions. Second, reading it from right to left starting at the point '100%=1990' indicates the abatement of carbon emissions (by emitters subject to cap-and-trade) relative to base year emissions. For illustrative purposes, the vertical supply curve is drawn for emissions equivalent to 95 percent of 1990 emissions, implying a decline in emissions of 5 percent relative to 1990. A tightening of the cap over time could be illustrated as a shift of the vertical supply curve to the left.

D_0 pictures a downward-sloping demand curve for emission permits. Demand is measured from left to right and, thus, demand is low for high carbon prices and *vice versa*. Each point on the demand curve reflects the cost of a carbon abatement (=mitigation) option – assumed to be continuous and linear for ease of exposition; options are shown in ascending order from right (low cost) to left (high cost). To illustrate, for a carbon price of, say, €20 per ton of CO_2, abatement options costing less than €20 would be exercised. Abatement would amount to, say, 2 percent of 1990 emissions and the demand for emission permits would equal 98 percent of 1990 emissions. The technology underpinning the 20-euro option could be, for instance, a wind farm in a location with favourable wind conditions. At a price of, say, €60/ton it is profitable to exercise all abatement options costing less than €60. Abatement would amount to, say, 25 percent of 1990 emissions and the demand for emission permits would equal 75 percent of emissions (for ease of reading, the diagram is not drawn according to scale). The technology underpinning the €60- option could be, for instance, a wind farm in a less favourable location.

Note that the demand curve includes the most basic abatement option one could think of: reducing or even terminating carbon-emitting production. To illustrate, for carbon prices above €20, production with an added value (per ton of CO_2) of less than €20 becomes unprofitable; production with an added value of more than €20 continues to be profitable and, thus, leads to a demand for emission permits. In sum, a fall in the demand for permits in response to a price increase is because low-carbon technologies substitute for high-carbon technologies (in the production of electricity, for instance) and because some carbon-emitting production ceases altogether. Equally important, an increase in the demand for permits in response to a price decline is because high-carbon technologies substitute for low-carbon technologies and because some carbon-emitting production increases.

The carbon market clears when demand for and supply of emission permits are equal. In diagram 1, this is assumed to happen at a price of €50.

Diagram 1

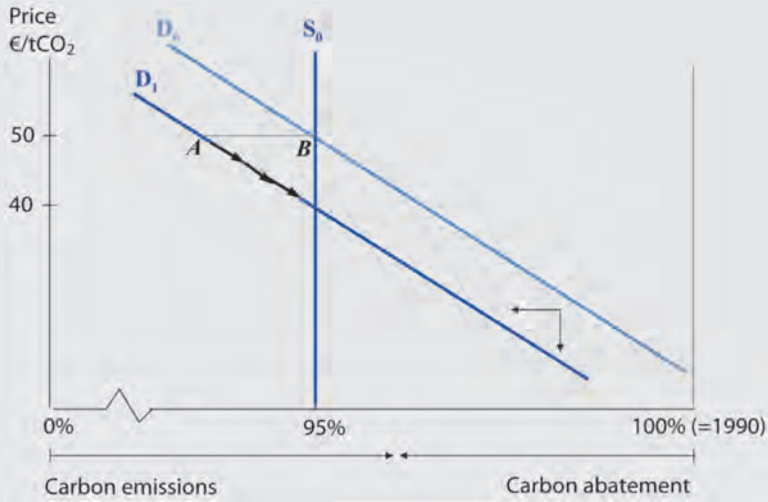


The effect of subsidising investment in low-carbon technologies and energy savings

Although not stated explicitly, D_0 in diagram 1 is meant to picture the demand for emission permits in the absence of public policies that influence the demand for them. The question, then, is how such policies – notably subsidies for low-carbon electricity and measures to curb electricity consumption – affect the demand for emission permits, emissions and the carbon price.

For a start, such policies reduce the demand for permits. In diagram 2, which replicates diagram 1 but leaves out unnecessary clutter, this is shown as a left/downward shift of the demand curve to D_1. Two complementary interpretations rationalise the shift of the demand curve, pictured as a parallel shift for simplicity. One looks at the shift to the left. To explain it, consider measures that cut electricity consumption – replacing incandescent light bulbs with fluorescent ones or energy efficiency standards, for example. All other things being equal, electricity producers demand fewer emission permits. The other interpretation focuses on the downward shift. Recall that the cost of abatement options determines potential emitters' willingness to pay for permits. Support for renewable electricity – be that *via* feed-in tariffs or investment grants – reduces the financial cost of the renewable-abatement option and thus lowers potential emitters' willingness to pay for emission permits.

Diagram 2



What is the impact of a fall in demand for permits on emissions and the carbon price? Starting from a 'without-subsidy' equilibrium with a market-clearing price of €50, the fall in demand leads to an excess supply of *AB*. *AB* indicates the emissions that subsidies help avoid if the carbon price remained constant. In fact, *AB* picture the cut in emissions in a world without cap-and-trade or if there was a carbon tax of €50 in lieu of cap-and-trade. In a cap-and-trade world, the freed-up emission permits of *AB* result in an excess supply that triggers a fall in the carbon price which, in turn, increases the demand for permits (as indicated by the arrow along D_1 in diagram 2). The fall in the carbon price comes to an end once the excess supply has been absorbed, that is, when all 'freed-up' permits have been bought. And they are bought to pursue carbon-emitting activities that are not profitable at a carbon price of €50, but become profitable at prices between of €50 and €40 – the new equilibrium price assumed here.

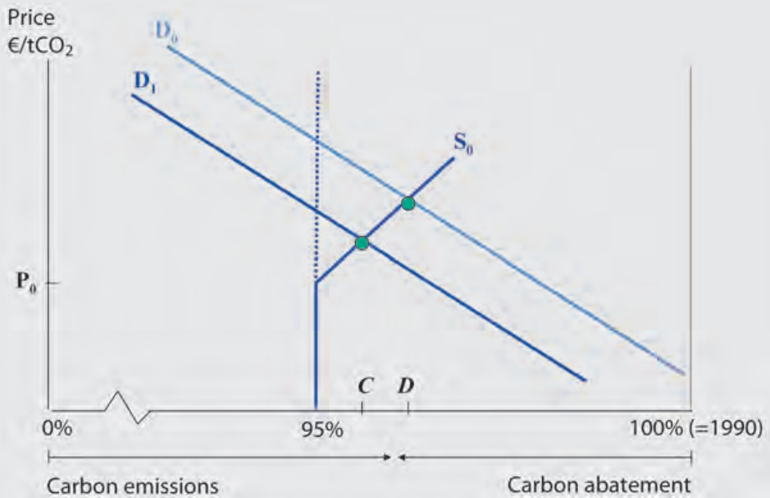
It is worth elaborating on the emissions that absorb those 'freed-up' by subsidies. As for the electricity sector, the decline in the carbon price tends to change the merit order of fossil fuel-fired power plants in favour of coal relative to gas, thereby increasing emissions. It also makes it worthwhile to defer the decommissioning of old, relatively inefficient and carbon-intensive plants. All in all, policies that lower the carbon price make the operation of an existing generation park more carbon intensive. What is more, a depressed carbon-price also biases investment decisions in favour of coal at the expense of environmentally less malign gas-fired power stations.

The slack created by the drop in demand does need to be taken up exclusively by the power sector. Carbon-emitting industries subject to cap-and-trade all benefit from lower carbon prices and emit more carbon than they would at a higher price. To conclude, the workings of cap-and-trade ensure that carbon emissions are equal to the cap. While subsidies in favour of low-carbon investment and energy savings affect the carbon price, they do not reduce emissions governed by cap-and-trade.

The analysis presented so far ignores that a cap-and-trade system might allow for carbon offsets generated outside its geographical boundaries, such as the Certified Emission Reductions generated under the Kyoto Protocol's Clean Development Mechanism, which are up to a certain amount allowed into the EU ETS. In contrast to the cap itself, the supply of carbon offsets rises with an increase in the carbon price. This is pictured by the kinked supply curve S_0 in the diagram 3, where P_0 indicates the cost of the cheapest abatement option outside the boundaries of the cap-and-trade system. The more the carbon price rises above P_0, the greater is the supply of carbon offsets. How does this affect the impact of a drop in the demand for permits?

As diagram 3 indicates, carbon prices fall, though by less than with a fixed supply of emission permits. Emissions within the boundaries of cap-and-trade fall and abatement increases by *CD*. However, as the supply of carbon offsets and, by extension, emission cuts achieved outside of cap-and-trade fall by the same amount, global emissions remain unchanged. Again, subsidies for low-carbon investment and energy savings do not reduce global emissions when they are granted for activities that are governed by cap-and-trade.

Diagram 3



To conclude, policies that reduce the demand for carbon permits cannot reduce global carbon emissions when the supply of permits is fixed and carbon offsets allow, by design, emissions inside a cap-and-trade system to increase by exactly the same amount as emissions fall outside it. For economists, this is a trivial result – though often overlooked by policymakers.

4.3.7 National industrial policy is fragmenting the market

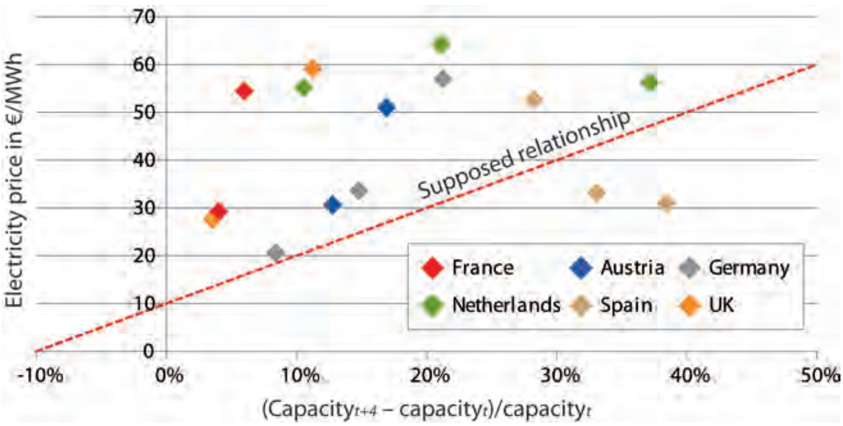
In addition to overlapping national and EU-level climate policies, national industrial policy is fragmenting the market for low-carbon technologies. A lack of coordination between member states results in different technological standards (such as for plugs for electric vehicles), hampering the competitiveness of European low-carbon technologies. National technology preferences are inconsistent. For example, battery electric vehicles (BEVs) are favoured by some countries (for example, Germany), while biofuels are favoured by others (for example, Sweden). While national preferences might be beneficial initially because they implicitly explore a wider portfolio of technology options, in the longer-run fragmented national industrial policies may result in an inability to compete with other non-EU countries in the race to develop low-carbon technologies.

Support for new low-carbon technologies involves large-scale public intervention. Anecdotal evidence suggests that corresponding political support is granted based on implicit local value content requirements. For example, the establishment of feed-in tariffs for renewables in a country is supported if the technology provider(s) promise(s) to shift some part of their production to this country. This is somewhat natural, but the line towards state-aid is narrow and *in extremis* it prevents effective specialisation and clustering of industries. Hence, national green industrial policies might constrain Europe's overall competitiveness.

4.3.8 Lack of a single energy market

Energy generation is responsible for about 30 percent of the EU's emissions.[96] Although the EU has a goal of the creation of a single energy market, it is far from being achieved. Fragmented member state markets have led to the absence of cross-border investment signals, resulting in excess costs and ineffective policies. For example, electricity companies in Europe time their investments in national electricity markets depending on the level of electricity prices. If wholesale prices are high, companies seem to be more likely to invest than if prices are low. This positive correlation is visible for Austria, France, Germany and the UK individually. However, on the European level, this intuitive relationship vanishes (see Figure 7). Even at high prices, capacity additions in France and the UK have been low, while the Netherlands added significant new capacity at high prices. Electricity companies in Europe do not seem to systematically invest more in countries with the highest prices. This indicates, that wholesale electricity prices are only a signal for timing investments within countries, but do not drive the location of power plants. Consequently, the development of the European power plant fleet is not driven by the single electricity market, but by differing national policies and regulations. It would therefore be surprising if (arguably uncoordinated) national policies and regulations resulted in an optimal transition from a high to a low-carbon fuel mix.

Figure 7: Price level vs. capacity addition after four years



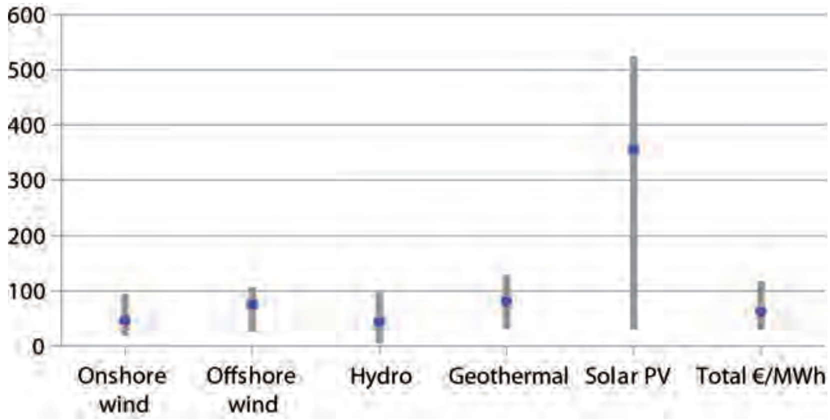
Source: Bruegel based on ENTSO-E, Datastream, Macrobond, DECC.

National renewable schemes illustrate this. As shown by Figure 8, the level of support varies widely in different member states. This makes greenhouse-gas mitigation through the replacement of fossil-fueled power plants by renewable sources significantly more expensive. For example, if the 25 gigawatts of subsidised German solar power had been installed in Greece, the value of the additional electricity generated due to the 50 percent higher level of sunshine would have been around €1.3 billion in 2011. As the sums are substantial (the net present value of future German feed-in tariff commitments in 2010 was about €100 billion – or 4 percent of GDP) significant economic benefits remain unused.

4.3.9 Summary

Although it is impossible to quantify precisely how far current climate polices are from the optimal growth-decarbonisation frontier (see Figure 4), it is

Figure 8: Renewable energy support in a cross-section of EU countries (low, mean, high in €/MWh)



Source: CEER 2011.

possible to identify reasons why the policy mix is far from optimal. Lack of a long-term carbon price signal deters investment in low-carbon technologies; fragmented global policies cause an inefficient geographic distribution of abatement efforts; overlapping policies may interact to create undesirable effects and raise the costs of abatement; high sectoral differences in the cost of carbon; and, an overall lack of coordination, result in costly EU climate policies that leave us far from the growth-decarbonisation frontier. Increasing growth while maintaining decarbonisation ambitions is possible with good policy.

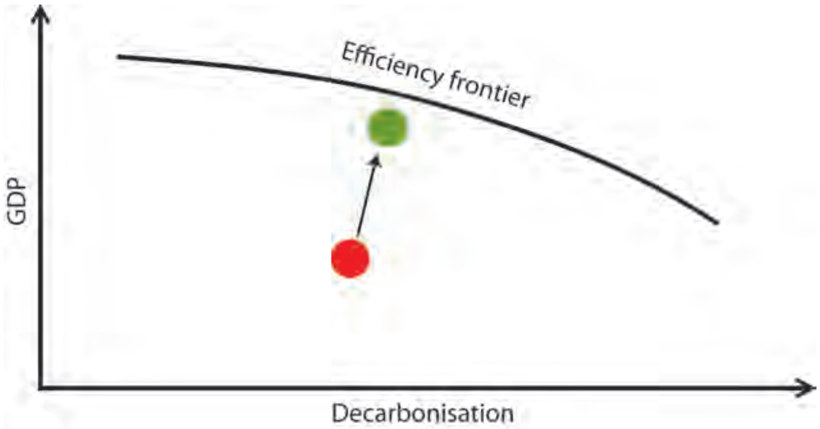
However, it is also clear that, in reality, the optimal frontier cannot be reached. The economically optimal level of harmonisation and coordination at the European level is politically unfeasible, because political constraints limit the transfer of sovereignty. Furthermore, national decarbonisation policy choices are made based on their national effects. The effects of decarbonisation policies differ markedly in different countries, because of differing initial conditions. Consequently, it is hard to avoid the emergence of inconsistent national policies. Finally, stakeholder trust in market mechanisms is limited and, hence, a certain degree of inefficient political micro-management is inevitable.

4.4 What are the guidelines for growth-friendly climate action?

Inefficiencies in current decarbonisation policies, as outlined in this chapter, mean that there is ample potential for accelerating economic development by making climate action more growth-friendly. The main prescriptions in the literature are to shift the focus from mere effectiveness to effectiveness and efficiency and to create credible long-term frameworks instead of micro-managing decarbonisation. However, political constraints call for second-best solutions.[97]

Put differently, this section asks how can we get closer to the growth-decarbonisation efficiency frontier (see Figure 9).

Figure 9: How can we get closer to the efficiency frontier?



4.4.1 Horizontal interventions to resolve externalities

Good policies should as much as possible restrain from micro-managing decarbonisation. Carbon prices and technology-neutral policies for overcoming the externalities hampering green investments should be implemented. According to Porter (1995), giving entrepreneurs freedom to comply with environmental regulations (*e.g.*, through using cap-and-trade systems) improves efficiency and increases the possibility that they come up with new solutions.

4.4.2 Enabling long-term investment

Decarbonisation policies essentially consist of replacing existing high-carbon capital by new low-carbon capital. The industries affected are characterised by very high capital intensity and long asset lifetimes. Consequently, it is essential to convince investors that typically more expensive low-carbon investment will be more profitable in the longer-term than high-carbon investment . The main problem is that the higher cashflow from low-carbon investment is based on political intervention (for example the carbon price, support schemes or regulated returns). Hence, investors face the risk that as soon as their irreversible investments have been implemented, policymakers change the policy framework in order to reduce costs for consumers and thus implicitly expropriate the investment and lock in the investor for decades. If the government fails to overcome the time-inconsistency issue there will be high risks for investors, who will only invest late or require substantive risk-premia for their investments. In addition, investments will be biased towards technologies that have a lower inherent risk (shorter amortisation, lower capital intensity, reversible). This would lead to inefficiently risk-averse investment decisions.

Helm has addressed the time-inconsistency issue and suggests that there are at least three different solutions. First, in Helm (2010), he suggests that the solution in the past for corresponding time-inconsistency problems has been the nationalisation of the corresponding industry. Second, Helm *et al.* (2003) propose an *"institutional solution to this problem, adapted from the monetary policy literature; the commitment outcome can be achieved through delegation to an 'environmental policymaker', akin to a conservative central banker."* Consequently, in general this implies transferring decisions to an independent technocratic body with a clear mandate. Third, Helm (2010) suggests that the time-inconsistency can be overcome by basing investments essentially on private contracts between the investor and either the government or consumers. In contrast to laws or regulations that might change, private contracts are enforceable for the investor and thus overcome the time-inconsistency to some degree.

Each of the three approaches has its merits and suitable areas of application. But, of course no single approach fits all problems. Nationalisation is certainly an option for countries with weak legal institutions but comes at the cost of efficiency losses inherent to government failure. Independent institutions require strong legal systems to ensure arms-length from the state. Regulatory capture is widespread and there is an inherent democracy deficit with this type of action because future generations are supposed to not change once-established target functions. Finally, private contracts with the state entail some micro-management of the system and are not completely renegotiation proof.[98]

An alternative for developed countries with stable institutions might be for governments to invest in reputation/credibility by writing into new policies voluntary compensation in case of changes of policy. Such a strategy is expensive (especially at the beginning) and the incentives to deviate are high for individual governments in short electoral cycles. In the long-term it could, however, be the welfare-maximising strategy for a country.

There is an interesting parallel: deviating from long-term commitments compares to defaulting on public debt. In the presence of a long memory of financial markets, the increase in the interest rate for public debt can have adverse consequences for governments in the medium run (Cruces and Trebesch, 2011). Consequently, creating a long-term stable environment and credibly promising to compensate any investor that might lose money when the framework is changed would reduce investment costs. It makes sense for society as a whole to keep a margin for manoeuvre with regard to long-term climate commitments in the face of complicated international negotiations, for example (see chapter 2). But society as a whole – and not only private actors that based investment decisions on commitments that might become inopportune for international climate-diplomacy (or other) reasons – should bear the cost of keeping this flexibility. As a by-product, a commitment to compensate investors affected by changes in policy would force policymakers to think harder about the long-term sustainability of their policies (especially if such commitments have to appear as liabilities on today's government balance sheets).

4.4.3 Stepping up the role of the EU ETS

The framework underpinning the long-term carbon price should be credible in order to support the major investments that are needed. Currently, the EU emission cap for 2020, the sectoral coverage, the institutional setting beyond

2020 and other key elements of the ETS are subject to change. Thus, the ETS lacks credibility and fails to provide clear long-term investment signals. Low emission allowance prices in 2011 are a telling example of the lack of confidence of investors in the current legislation. If market participants had confidence in the stipulated tightening emission cap beyond 2020, the future scarcity of bankable allowances should stabilise the price today. Hence, the short-term oversupply of bankable allowances (resulting from the economic crisis and emission reductions caused by energy efficiency and renewables policies) would not lead to dramatically deflating prices.

A **broad** emission trading scheme providing a single carbon price across sectors would ensure cost-optimal abatement. Including additional sectors in the ETS is thus essential. For domestic heating and transport, this could take the form of obliging fuel outlets to buy emission allowances for the fuel they sell. This would result in the harmonisation of the carbon price across sectors and would provide an incentive for the use of the cheapest available abatement options. Several studies (Aghion *et al.*, 2011; OECD, 2011) show that a carbon price in transport might also provide an incentive for innovation in this sector. The inclusion of additional sectors in the ETS would increase the depth of the carbon market and make the system more resilient.

A **long-term** inter-sectoral coordination tool for decarbonisation is important. Because it might be politically and institutionally impossible to establish a credible long-term commitment to a tight emissions trading system in the absence of an international agreement (the 70 percent decarbonisation pattern implicit in the ETS does not, for example, match the stated European decarbonisation need of 80-95 percent in 2050), second-best options for creating investment certainty could be considered. Thereby, general frameworks to tighten or make more credible the ETS would be clearly preferable to the approaches that envisage supporting individual investments that are uninvestible at the current carbon price. A carbon floor price might seem attractive to today's low-carbon investors. It could, for example, be established through a reserve price on ETS allowance auctions, a tax on carbon that kicks-in if the carbon price is below the floor price, or open market interventions in the carbon market. However a general floor price is a rather inflexible tool. In case future carbon reduction potential turns out to be much cheaper than anticipated (*e.g.*, because of new technologies or lower economic growth) a high floor price could result in carbon reductions becoming needlessly expensive. For example, if a cheap technology for carbon-free power production emerges, continuing to expensively abate emissions by using biofuels instead of kerosene in the aviation sector might become inefficient because the additional cost might be completely disproportionate to the benefit. In addition, a politically set floor is subject to change and hence not credible in the long term (see the discussion in chapter 2 about the need to reserve some margin of manoeuvre in international negotiations).

A more targeted alternative in the face of political and technical uncertainty could be bilateral option contracts between public institutions and investors. The public institutions would guarantee a certain carbon price to an investor. In case the actual carbon price is below the guaranteed price, the public institution (the option writer) will pay the difference to the investor (the option holder).[99] Hence, in case of a low future carbon price, the investor will receive some implicit compensation for the loss of economic viability of his low-carbon investment, reducing his risk. At the same time, all actors will still have the right incentive to base their short-term decisions on the market price for carbon and not on the strike price of the publicly issued options. Thus, even investors with an option contract will have an incentive to optimise their behaviour with respect to the correct price.

At the same time, if the public institution issues a large volume of option contracts, it creates an incentive not to water down future climate policies. Policies that reduce the carbon price will have a direct budget impact by increasing the value of the outstanding options. This would tend to increase the long-term credibility of carbon policies for all (also the non hedged) actors.

4.4.4 A framework for supporting green R&D

There is a triple green innovation externality. First, innovative activities by one company have positive spillovers to other companies that could appropriate some of the results without having paid for the R&D. Second, new low-carbon technologies help to reduce the greenhouse-gas emissions in countries that have stringent emission regulations. And third, low-carbon technologies developed for countries with a stringent carbon price regime could be applied beyond the borders of this carbon pricing scheme and help reduce emissions elsewhere (*e.g.*, renewables in China).

Box 5: Compensating for innovation externalities – an example

To illustrate this with a numerical example: assume that for an equipment manufacturer, developing a technology that reduces the carbon emissions from cement production would cost €50 million. The new low-carbon technology has marginally lower variable and fixed costs compared to the incumbent technology. A competitor could reproduce the innovation for no cost. The market for the technology is completely competitive, that is no producer of the equipment is currently making any profit on selling the incumbent dirty cement-production equipment. The social cost of carbon is €25 per ton. If fully rolled out in the domestic market, the clean technology might reduce emissions by one million tons. In the foreign market, it can reduce carbon emissions by another one million tonnes. Hence the social carbon value of the innovation is €50 million.

If there is a domestic carbon price of €25/ton the domestic customers for the equipment (*i.e.*, the cement producer) would be willing to pay up to €25 million more for the low-carbon equipment (one million tonnes times €25). If the equipment manufacturer could extract the entire carbon rent, another €25 million in subsidies would still be needed to provide him with the incentive to carry out the €50 million R&D effort.

In case patent protection is imperfect and only one competitor might reproduce the technology at zero cost, the two companies would essentially share the equipment market. In this case an additional compensation of €12.5 million would be necessary to compensate the innovator because he will only obtain half of the domestic environmental rent.[100]

Consequently, multiple tools are needed to obtain the optimal level of green innovation. First, intellectual property rights need to be enforced to give private innovators an incentive to invest in R&D. If protection is imperfect, additional compensation is necessary. Second, a sensible long-term carbon price is necessary to provide a price signal that directs investment away from high-carbon towards low-carbon technology. Martin *et al.* (2011) show that the ETS has resulted in some innovative activity. Third, public support for innovation is necessary in case the benefits of low-carbon innovation beyond the borders of the ETS are not compensated for by foreign carbon prices.

Beyond this, additional compensation in the form of R&D subsidies might be warranted if innovation leads to additional positive externalities. If, as in Aghion *et al.* (2011), individual innovative activity is needed to build the technologies on which future technologies (developed by competitors) might be based, the value of this basic innovation should also be compensated for.

The right *method*, *timing*, *amount* and *allocation* of support are difficult to determine. This crucial field is critically under-researched.

The main *methodology* question is whether to push or to pull. As discussed in the first section, 'push' signifies public support directly given to innovative activity, while 'pull' means that the deployment of a technology is supported and thus private actors are indirectly given an incentive to innovate. So far, push strategies are more used in the early development phases, while pull strategies are more often found for supporting technologies at the demonstration stage (see the discussion on support for hybrid versus support for battery vehicles in section 4.2). Push is more effective in stimulating innovation inside the country. For example, Dechezleprêtre and Glachant (2011) show that inventors respond to both domestic and foreign new capacities by increasing their innovation effort. However, the effect on innovation of the marginal wind turbine installed at home is 28 times greater than that of the foreign marginal wind turbine. Public R&D expenditures only affect domestic inventors. In contrast, pull strategies also provide incentives for foreign companies to innovate. One example for this spillover is that the German support for the deployment of solar panels attracted substantial imports of such panels. In fact, the production cost of these panels fell more sharply in Asia than in Germany.

On the *timing* of support, learning-curve models have been used to predict optimal support patterns. Learning curves, however, only present a weak and largely atheoretical empirical relationship between the deployment of a technology and the unit cost/capability of the technology. Their estimation is confronted with significant margins of uncertainty.[101] There are also neither comprehensible rules on the appropriate *amount* of support, nor is there a conclusive literature on the *allocation* of the funds to the different technologies.

If a policy-support tool that guides decisions is lacking, choices about timing, method, amount and allocation of support for innovation in low-carbon technologies are largely based on *ad-hoc* judgments. It is unlikely that the current shot-in-the-dark approach is generating efficient choices. Furthermore, the absence of a transparent framework for the choice of support instruments is creating substantial uncertainty for potential innovators. The development of appropriate policy support tools is thus crucial. A lower degree of uncertainty would enable the level of innovation to be increased (OECD, 2011); a more model-based allocation mechanism could also improve the targeting of support. Hence, more and better innovation could drive growth.

4.4.5 Completing the internal market

International and intra-European trade in goods and services can significantly reduce the cost of decarbonisation by reaping the gains from regional specialisation. Completing the single market for energy is thus an important step for reducing the cost of decarbonisation. A functioning single market would enable energy companies to base their location decisions on the regional access to consumers and the availability of resources (*e.g.* wind or sun). A single energy market would require foreign and domestic producers to be treated equally. Hence, foreign producers must be allowed to participate in all energy market components. This is important because in times of increasing shares of intermittent renewable sources, the importance of the wholesale market electricity trade is declining. Trading electricity at short notice to balance unexpected short-falls in renewable production, or payments for power plants that are kept in reserve for exceptional circumstances, are becoming more important. Hence, international integration of these markets is essential in order to achieve a low-cost power-market transition. In addition, implicit energy subsidies should be replaced by targeted social assistance – in order to align energy efficiency incentives.

Beyond the energy market, other parts of the green internal market should also be stepped up. Implicit and explicit state aid to domestic green-technology firms should be closely monitored, and local value provisions evaluated. Otherwise national decarbonisation will not be driven by low-cost considerations but by the vested interests of industries and regions. This could hamper growth.

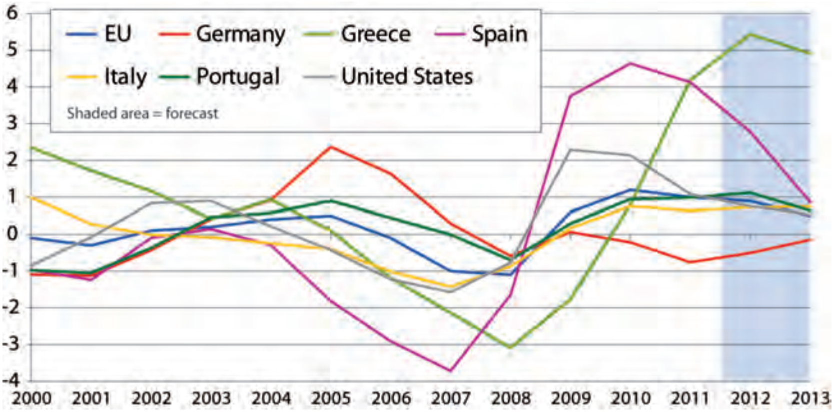
4.4.6 Considering the macro-dimension of investment in decarbonisation

In current crisis, fiscal easing is discussed mainly as a tool to restore growth in the EU's southern periphery. The proponents of this approach claim that without fiscally supported growth, these countries will not be able to reduce the share of debt relative to GDP. If GDP rises, this share drops and repaying the debts becomes easier. The opponents of fiscal easing claim that austerity is more important in the current situation because the crisis is largely structural and the low aggregated demand does not represent a cyclical depression.

Irrespective of this discussion, fiscal stimulus policies were used by many countries in the 2008 crisis (and before), and will continue to be used in future crises. If one follows the theory, overcoming cyclical crisis with demand stimulus would not only help to overcome the crisis in the short-term. Long-term potential growth could at the same time be increased if the publicly-driven increase in aggregate demand is targeted at productive investments. As discussed in section 4.2, demand stimulus policy is only effective if it focuses on countries that face a surge in cyclical unemployment. Consequently, decarbonisation policies that intend to give a welfare enhancing stimulus to labour demand have to be placed and timed right. At present, unemployment (with a certain cyclical component, see Figure 10) is strikingly high in the EU's southern periphery, while countries such as Germany have almost full employment. Unemployment in Greece, Italy, Portugal and Spain has been steadily increasing since 2008 and risks further increases. This might affect the long-term growth prospects of these countries because at some point cyclical unemployment risks becoming structural. For example, the skills of unemployed workers are gradually lost or become obsolete (hysteresis).

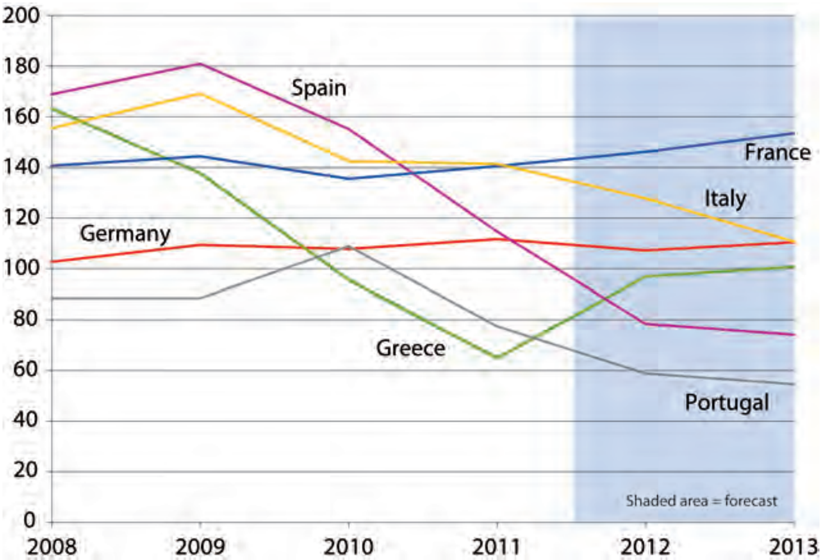
The cyclicality of unemployment is mirrored by public and private investment cycles (see Figures 11 and 12).[102] As the crisis-hit countries are

Figure 10: Cyclical unemployment in the southern periphery countries as well as Germany and the EU



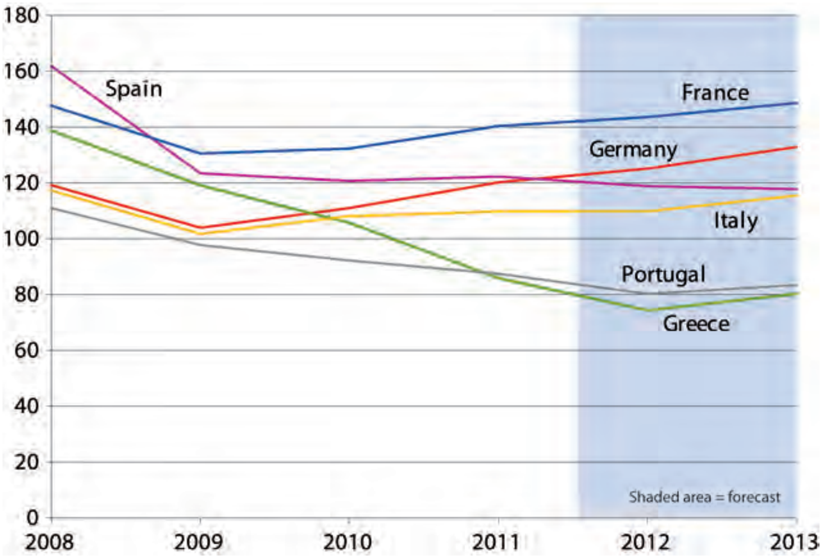
Source: Bruegel based on AMECO data as of May 2012.

Figure 11: Government investment (2002=100)



Source: EC AMECO database as of May 2012

Figure 12: Private sector investment (2002=100)



Source: EC AMECO database as of May 2012

part of the euro area, a main driver of the private sector's countercyclical investment decisions no longer applies: in times of cyclical downturn, national monetary policy was able to reduce the real interest rate. When monetary policy is no longer national (as in the euro area), national differentiation of interest rates in response to asymmetric shocks that only hit a part of the currency area becomes unfeasible. Hence, interest rates can no longer act as national stabilisers.

As a consequence of the asynchronous cyclical developments in Europe, extra stimulus in Germany would be more likely to result in overheating than a welfare-enhancing reduction in cyclical unemployment. In the southern periphery the inverse might be true.

As suggested in the first section of this chapter, demand-stimuli based on additional spending on sensible long-lived green investments have the side-benefits of creating the basis of future growth and assisting with decarbonisation. As it is assumed that most of the decarbonisation in the next few decades in Europe will come from the energy sector, investments in long-lived energy sector assets are a good candidate for demand stimulus. Furthermore, Table 2 indicates that GDP cycles and energy sector investment cycles show no clear correlation. Thus, energy sector investments appear a-cyclical – that is they neither automatically stabilise the business cycle,[103] nor do they move along with the business cycle.[104] Therefore, making energy sector investments counter-cyclical to some degree would help to stabilise the business cycle.

Table 2: Correlation of energy investment cycles with GDP cycles 1970-2011

	Correlation
France	-5%
Germany	4%
United Kingdom	-27%
United States	15%
Italy	23%
Spain	6%

Source: Bruegel based on OECD STAN Gross fixed capital formation (current prices) in electricity gas and, water supply, Methodology: HP cycle of deflated data (GDP deflator).

Energy sector investments have a significant order of magnitude. The total system capital cost was estimated in the range of €1,000 billion per year – or about 8 percent of EU GDP – for all scenarios by the European Commission in its Energy Roadmap (see Table 3). The greatest share of these investments is, however, private investment, including investment in vehicles and other energy-consuming appliances.

If one narrows down the scope to investment in the electricity sector – a sector that is supposed to play a major role in the decarbonisation of the European economy – investment figures become much smaller (see Table 4). They will range from €84 billion per year in the current policy initiative scenario, to €135 billion per year in a high renewables scenario. This order of magnitude represents around 1 percent of EU GDP. About one third of this investment is supposed to go into electricity grids[105] that are typically provided by public or

Table 3: Future energy sector investment cost scenarios from the EU Energy Roadmap 2050

Average annual total energy system capital costs 2011-2050 (€bn, 2008)							
	Ref	**CPI**	**High Energy effic.**	**Div. supply techn.**	**High RES**	**Delayed CCS**	**Low nuclear**
Energy system costs, of which:	983	1031	1410	1260	1253	1255	1265
- Capital costs	955	995	1115	1100	1089	1094	1104
- Direct efficiency inv. costs	28	36	295	160	164	161	161

Source: EU Energy Roadmap 2050 impact assessment.

private companies based on tariffs regulated by independent regulators. Around two thirds of the electricity sector investment is supposed to go into generation. These power-plant investments are conducted by both private and state-owned companies. The investment decisions on power plants are based on a number of market drivers (expected demand, fuel costs, competition, emission allowance prices, etc.) and a number of factors that can be directly influenced by governments (subsidies for certain generation technologies, taxation, market design, etc.). Hence, governments might use counter-cyclically timed incentives to bring forward or delay energy sector investment. In fact, large-scale government intervention to stimulate additional investment in the electricity sector is already happening/planned in various countries. One main purpose of the UK market reform is to ensure a certain level of power-sector investment in the coming decade, and German feed-in tariffs and the nuclear phase-out decision have created significant incentives for private market participants to invest.

National energy policies are quite volatile. Support schemes for renewables have been significantly slashed during the crisis. Italy for example reduced its support for large photovoltaic installation on buildings by 35 percent in the second semester of 2012, compared to the level in June 2011. In 2010, the Spanish government decided to slash the feed-in tariff for photovoltaic plants from 25-48 eurocents per kWh to 13-29 cents/kWh for systems installed after 29 September 2008. As a consequence, investment in new capacities has been significantly reduced. Consequently, fiscally constrained

Table 4: Future electricity sector investment cost scenarios from the EU Energy Roadmap 2050

Average annual total investment costs for the electricity sector 2011-50							
	Ref	**CPI**	**High energy effic.**	**Div. supply techn.**	**High RES**	**Delayed CCS**	**Low nuclear**
Total electricity sector investment costs, of which:		84	92	104	135	107	107
1) Grid investiments (€bn, 2005):							
Total grid investment costs, of which:	32	34	38	43	55	43	45
- Transmission grid investment	5	6	7	7	11	7	8
- Distribution grid investment	27	28	31	35	44	35	37
2) Power generation (€bn, 2008):							
Average investment expenditure in 2011-2050 for power generation		50	54	61	80	64	63
Broken-down by technologies (as % of net power capacity investment in GWe 2011-2050):							
- Nuclear energy	11%	9%	5%	7%	2%	8%	1%
- **Renewable energy**	50%	54%	70%	68%	80%	69%	71%
- Thermal power fossil fuels	33%	32%	17%	19%	11%	17%	22%
of which: CCS	6%	2%	9%	10%	2%	8%	13%
- Thermal power RES	6%	6%	7%	6%	7%	6%	6%

Source: EU Energy Roadmap 2050 impact assessment.

policymakers in crisis-hit countries appear to make energy investments more pro-cyclical and hence increase regional disparities by reducing the incentive for investment in worse-off regions.

However, electricity is supposed to flow relatively freely within Europe, and the crisis-hit countries should have no clear comparative disadvantage in electricity production (in some technologies, such as solar, they might even have an advantage), so it would be sensible from a macroeconomic point of view to encourage investors to target their green generation investments at countries facing cyclical downturns.

This could be achieved by pooling the support to the deployment of clean generation technologies at European level. Europeanisation of the support to renewables alone would help to reduce the national pro-cyclicality of the corresponding investments. *In extremis* one could even consider that support for renewables generation could be handed out with priority given to countries that face a cyclical downturn. For example, in temporarily eligible countries, renewable generation investors might be granted a top-up to the harmonised support level. A readily-available technical criterion for deciding whether a country is eligible for this top-up could be the level of cyclical unemployment. As all countries are supposed to run through the different phases of the business-cycle, any country will at some point benefit from such a top-up. A transparent and credible framework would shape private sector expectations. If the top-up is of a meaningful order of magnitude, investors would react by delaying renewables investments that only just break even in booming countries, while bringing forward renewables investments that almost break even in crisis countries. The efficiency of using decarbonistion investments to asymmetrically affect the business cycle is conditional on the existence of a harmonised European renewables support scheme. Otherwise, any European level top-up to national renewables support would risk merely crowding-out national support schemes (*i.e.*, a country in difficulties reduces its support to investments when the EU provides support to investments in a country).

Helm (2011) argues that network infrastructure investments would make for a good stimulus programme. They are significant in size, mainly state-driven in any case and might in the future be countercyclically timed. Governments have the option to increase/decrease the incentives for investment aimed at private (and public) transmission system operators. In Germany for example, a top-up of the rate-of-return on certain new transmission lines was agreed politically in order to speed up the roll-out of these lines. For investment in transmission network infrastructure that is needed for a low-cost decarbonisation of the European energy sector, the argument has been made that (parts of) it should be funded at European level. With a European mechanism, the source of funding (individual tariffs) and the destination of funding (investment projects in different parts of Europe) do not always need to match geographically. Hence, again, a transparent scheme that that enables non time-sensitive network investments to be primarily made in phases of regional cyclical downturn could help better accommodate asymmetric shocks in the euro area.

4.4.7 Conclusion

Decarbonisation will require significant further government intervention in sectors in which there is already strong political involvement, in order to overcome the inherent externalities. Smart interfaces between the public and private sectors are a requirement for growth-friendly decarbonisation. Therefore, decarbonisation should be pursued not only by inventing new policies but also by adapting old policies that currently conflict or pursue complementary targets.

Policies that are targeted at short-term effectiveness might be detrimental to long-term growth. Consequently, a clear long-term framework is essential for coming close to the optimal pattern of instantaneous mitigation, investment in assets and innovation to reduce future mitigation cost. This includes a framework for supporting low-carbon innovation, a carbon price signal that investors can rely on and a credible investment environment. This does not, however, mean that short term intervention is *per se* detrimental. Implementing large-scale investment projects for a low-carbon future can provide a welcome stimulus for regions with high cyclical unemployment.

To shift the focus from short-term effectiveness to long-term efficiency, all instruments for climate action should pass a growth-friendliness test.

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CHAPTER 5

Common threads and a little soul-searching

Armin-D. Riess and Georg Zachmann

Each chapter of this volume presents its main findings in a 'chapter at a glance' summary, and in its concluding section. It is not necessary to go over this ground again in an overall conclusion. Rather, it seems more enriching to, first, highlight two themes common to all chapters and, second, to reflect on a possible change of mind in the time of climate change.

The first common theme is that climate change poses a resource allocation challenge like few others. When allocating resources to climate action and other uses, society faces a variety of complex trade-offs. Most obviously, there is the trade-off between a safer climate in the future and more consumption today. There is broad agreement that it is sensible to forgo some of today's consumption in return for a safer climate. The choices are harder when considering the trade-off between a safer climate and increased future consumption. This trade-off arises because resources allocated to climate action today might be at the expense of an expansion of the productive capital stock that will determine the extent of future consumption options. Finally, assessing trade-offs indeed becomes daunting when the choice is between climate action and spending in areas that many people would find worthy of receiving a bigger share of resources, such as research and development, healthcare and conflict prevention and resolution.

Climate action itself requires choices to be made between competing tools and approaches. There is the very basic choice between mitigation and adaptation. Though both are needed, society can spend its proverbial last euro either on cutting greenhouse-gas emissions or on adapting to climate change, not both. When it comes to alternative mitigation options, the same applies: while society will most likely opt for a portfolio of low-carbon technologies (including wind, solar, nuclear and carbon capture and storage), it needs to decide on the structure of this portfolio, weighing the pros and cons of all technologies. Similar tensions permeate the choice of adaptation measures, which the dichotomy of proactive versus reactive adaptation shows most clearly: is it better to anticipate climate change and prepare for it in advance or, alternatively, wait and cope with climate impacts as they arise?

Answering this question – the quest for appropriate climate action more generally – is difficult. The answer needs to be found in an environment characterised by deep uncertainty; possibly big, abrupt and catastrophic climate change; and the irreversibility of the stock of greenhouse gases in the atmosphere. Equally importantly, the answer crucially depends on how much weight is given to the welfare of future generations relative to the welfare of current generations. This weight depends on economic considerations, but also hinges on ethical judgements. The more today's generation cares about the welfare of future generations, the more it should invest in cutting emissions. If this appears too obvious a choice, it should not be forgotten that about two billion people today live in dire poverty and doing more today for a safer future climate absorbs resources that could be used to fight poverty here and now. This substantially qualifies the seemingly agreeable statement made above that it might be easy to choose in favour of climate action if it comes at the expense of consumption. The thorny question is: whose consumption?

In sum, society faces dreadful choices and trade-offs, but this is in the nature of both ethics and economics. Writing about individual and social rationality, Arrow (1974, p.17) emphasised that *"The role of economist here is sometimes unpleasant … We frequently have to point out the limits of our opportunities. We have to say, 'This or that, not both. You can't do both'".* Undoubtedly, climate change further tightens the limits of our opportunities.

The second theme common to all chapters is the role of governments. Regardless of the degree of climate action that society might wish to see, markets left to their own devices will not deliver it because of a variety of externalities, behavioural failures, barriers to investment and other market failures. Of particular importance are the negative climate-change externality of greenhouse-gas emissions, and the closely-related collective-action problem of reaching an international agreement to cut emissions. There is thus a role for government policies to help overcome these obstacles and to work towards meeting climate objectives at least cost.

The economic policy toolbox contains a range of policy instruments. The challenge for policymakers is to choose well from them. A telling if perhaps politically incorrect way to illustrate the challenge is to ask if it is possible to kill two birds with one stone, how many stones might be necessary to kill one bird, and which stones to throw? The seminal work where the quest for answers can begin is Tinbergen (1956), who established that the number of independent policy tools must be at least as high as the number of policy objectives.

The 'Tinbergen rule' thus limits the scope for hitting two targets in one go, say, cutting greenhouse-gas emissions and boosting economic growth with a tax on emissions. While taxing emissions causes them to be reduced and indirectly stimulates innovation and production in low-carbon industries, the tax itself does not encourage aggregate economic activity – though using the extra tax revenue wisely might.

Whether it could make sense to throw more than one stone at a bird cannot be answered unambiguously, but typically it seems best to assign one policy instrument to one policy objective. One idea running through this report is that Europe's climate action is more costly than it could be – not only because of mistaken beliefs that two birds can be killed with one stone, but also because too many instruments are employed in situations where one would do, provided it is the right one.

Choosing the right policy instrument and its scale – the appropriate type and size of stone – is difficult and controversial. Reflecting the diversity of possible market failures and barriers, optimal climate action needs to judiciously blend market-based instruments, public supply of goods and services and government regulation. In principle, the main ambition should be to choose the policy mix that delivers climate objectives at least cost. That said, given the economic downturn and strained government budgets in many EU countries, the consequences for economic activity and public finances of the choice of instrument must be recognised. This might again involve trade-offs. But as this report emphasises, there are win-win opportunities, too, such as making greater use of policy instruments that cut the economic cost of meeting climate objectives and contribute to economic growth and fiscal consolidation.

All in all, looking at Europe's climate policy landscape and the role of governments in shaping it, this report argues that there is considerable scope for making climate policies more efficient, growth-friendly and in tune with fiscal constraints.

To end with a reflection on a possible change of mind in the time of climate change, it is useful to recall that this report has been deliberately narrow in its approach, taking an economic and European perspective. What is more, a key theme has been how climate investment can be encouraged while maintaining economic growth. Maintaining growth and raising living standards is an undeniable aspiration of the bulk of people in the less-developed world. But can one confidently claim the same for the majority of people in advanced economies, in particular, if global economic growth cannot be sufficiently decarbonised so that dangerous interference with the climate is avoided?

Against this background, it is instructive to distinguish between 'luxury emissions' and 'survival emissions' (Agarwal and Narain, 1991). It is probably fair to consider the bulk of greenhouse-gas emissions in advanced countries as luxury emissions compared to emissions caused by people struggling to grow out of poverty in the developing world. What is to be done if it is not possible to reconcile inevitably higher survival emissions with continuously high or even rising luxury emissions?

One option, utopian perhaps, might be for mankind to tame its longing for a perpetually growing supply of material goods and services and to seek other means to ensure its well-being. In his fascinatingly rich exploration of climate change, Mike Hulme distinguishes between climate change *per se* and the idea of it and he suggests that *"The idea of climate change should be used to rethink and renegotiate our wider social goals about how and why we live on this planet"* (Hulme 2009, p. 361). Whether we want to rethink or not, manmade climate change might force us to.

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Notes

Chapter 1: Setting the scene

1 At present, global greenhouse-gas emissions are governed by the Kyoto Protocol, which commits only a subset of countries – mainly industrial countries except for the United States – to collectively cut their average 2008-12 emissions by 4.2 percent relative to 1990. In December 2011, Canada formally withdrew from the Protocol. Efforts to reach a considerably more inclusive agreement continue. At the 2011 Durban climate change conference (one of many successors to the 1997 Kyoto conference), all countries committed to negotiate a new treaty by 2015 and put it into force by 2020. The envisaged treaty foresees emissions reduction targets for all countries.

2 The notion of mankind's dangerous interference in the climate system originates in Article 2 of the United Nations Framework Convention on Climate Change: http://unfccc.int/essential_background/convention/background/items/1349.php

3 A substantial literature exists on the economics of climate change: indeed it is perhaps more accurate to describe it a core research area of modern economics. Several excellent textbooks (*e.g.*, Kolstad 2009) and survey articles exist (see Helm and Hepburn 2009). This section draws on the influential – and controversial – Stern Review (2007) and Stern (2008); as well as a very readable book by Nordhaus (2008) and two recent survey papers by the same author (Nordhaus 2011a, 2011b).

4 See the annex to chapter 3 of Stern (2007) for an overview of issues surrounding the social discount rate.

5 More precisely, the temperature sensitivity coefficient is assumed to be 10°C per doubling of CO_2 concentrations and the damage function is highly convex, from a threshold of a 3°C increase on pre-industrial temperatures.

6 Other greenhouse gases include methane, nitrous oxide and fluorinated gases such as sulphur hexafluoride. Their global warming potential differs enormously. To illustrate, 100 years after their release, the global warming potential of one tonne of methane is 25 times greater than the warming potential of one tonne of carbon dioxide (CO_2); for sulphur hexafluoride, the multiple is 22,800. To aggregate greenhouse gases with different warming potential, the volume of non-CO_2 emissions is converted into CO_2 equivalents – CO_2eq for short. Based on the volume of emissions and differences in warming potential, data in Figure 3 show emissions in gigatons (Gt) of CO_2eq.

7 Alternative ways of sequestering greenhouse gases are sketched out in

chapter 3.

8 For instance, Christiana Figueres, executive secretary of the UN Framework Convention on Climate Change, has argued that "*Two degrees is not enough – we should be thinking of 1.5°C. If we are not headed to 1.5°C we are in big, big trouble*." See for example: http://www.guardian.co.uk/environment/2011/jun/01/climate-change-target-christiana-figueres

9 European Council, 4 February 2011, conclusions. http://www.fransamaltingvongeusau.com/documents/cw/EC/136.pdf

10 There are other sources. For instance, the International Energy Agency regularly examines energy-sector investment needs – globally and for groups of countries. For the world as whole, IEA (2009) calculates that transforming the traditionally carbon-intensive energy sector into a low-carbon one would require additional investment of $750 billion per year in 2010-30 and $1,600 billion per year in 2030-50. Note that IEA and European Commission estimates are not comparable, however. For one thing, the country coverage differs. For another, European Commission estimates are for energy-related investment, a broader concept than energy-sector investment.

11 To facilitate comparison, note that European Commission (2011d) labels the first type of investment 'capital cost' and the second type of investment 'direct efficiency investment cost'. The terminology 'investment' is used here for brevity to capture energy-related expenditure of a capital nature. That said, note that national accounts do not record all of these expenditures as investment. Most obviously, household expenditure on energy-using appliances and vehicles is treated as consumption, not investment. Note, too, that the figures presented here comprise demand- and supply-side investment.

12 Although illustrative, these are not investment-to-GDP ratios for the reason given in the previous footnote. Moreover, they do not account for the time profile of investment and GDP over the period 2011-50.

13 The model is a static, computable general-equilibrium (CGE) model. In essence, it represents the effects that climate change expected to happen by 2080 would have on today's EU economy if these impacts were to happen today.

14 There are five different climate-change scenarios associated with four different global average temperature increases: 2.5°C, 2.9°C, 4.1°C, and 5.4°C. The fifth scenario is also for 5.4°C increase in temperature, but a higher sea-level rise (SLR) is assumed.

15 One of the main criticisms is that the model simply projects expected climate change in 2080 on to today's economy; the evolution over time until 2080 was not taken into account – neither for climate change nor for the economy.

Chapter 2: Mitigate, adapt or endure: A question of balance

16 See UNFCCC Glossary on http://unfccc.int/essential_background/glossary/items/3666.php.

17 Pascal *et al.* (2006) provide a full description of the system's design and implementation.

18 Mitigation and abatement of greenhouse-gas emissions are considered synonyms in this chapter and, therefore, this definition also applies to the abatement of greenhouse-gas emissions.

19 This is, of course, true for democracies. In a democratic country, the ruling party could deviate from its election promises, but it cannot do so consistently.

20 Adaptation and mitigation are each treated here as a single activity. Admittedly, there is a variety of adaptation and mitigation measures and it is certainly not the case that each particular adaptation measure is a substitute for each and every mitigation measure, or *vice versa*.

21 Here costs include not only forgone consumption, but also lost species, irreversible changes in the environment, stress induced by living in adverse environment *etc*. Admittedly, the majority of these are very hard to estimate and quantify in units (say monetary units) that are comparable across categories.

22 Emissions can be negative if the amount of greenhouse gases leaving the atmosphere is higher than the amount of gases entering it. In theory, this is possible by increasing the capacity of carbon sinks. The largest carbon sinks are the soils, oceans and forests.

23 Work by V. Bosetti, C. Carraro and co-authors is a notable exception. See for instance Bosetti *et al.* (2006), Bosello *et al.* (2010), or Bosello *et al.* (2012).

24 AD-WITCH adds an adaptation module to the WITCH – World Induced Technical Change Hybrid – model (see www.witchmodel.org). The adaptation module (AD) is sketched in the Annex to this chapter and described in further detail in Agrawala *et al.* (2011).

25 To the extent that there is some ability of adaptation to substitute for mitigation, it is due to the fact that mitigation not only reduces catastrophic risk but also the (smooth) damage from climate change.

26 See the chapter Annex for more details on how Bosello *et al.* (2012) model different types of adaptation.

27 If unsuccessful, leading by example may simply lead to emissions moving from leading countries to the rest of the world, thereby resulting in little or no decrease in global emissions. The European Commission (EC) takes this issue seriously, noting in its EU Energy Roadmap 2050 (2011, p.9) that "*Safeguards against carbon leakage will have to be kept under close review in relation to efforts by third countries*."

Chapter 3: Boosting climate investment

28 See Mas-Colell *et al.* (1995), for instance.

29 The last group of mitigation investment is discussed, too, as one of two broad climate engineering options. See The Royal Society (2009) and Bickel and Lane (2009), for instance. While climate engineering is not yet part of the climate policy toolbox, an increasing number of scientists are examining its potential not least because of its apparently attractive economics (in addition to Bickel and Lane (2009) see Barrett (2008)).

30 In the introduction, a distinction was made between low-carbon energy technologies (used in energy, transport, industry, and so on) and technologies aimed at reducing non-energy greenhouse-gas emissions associated with industrial processes – carbon dioxide emissions resulting from the chemical conversion process used in the production of cement, for instance. In what follows, both types are subsumed under the heading low-carbon technologies. Similarly, the term high-carbon technology is meant to capture both types of carbon-intensive technologies.

31 For a brief review of the economics of asymmetric information and its impact on a variety of markets see Hillier (1997), for instance.

32 The annex at the end of this chapter sketches how to value such options.

33 The behavioural economics literature speaks of behavioural tendencies rather than failures. Indeed, behavioural economics holds that the concept of rational and self-interested agents is a misrepresentation of reality. Pioneers in behavioural economics include Daniel Kahneman, Amos Tversky and Richard Thaler. For an introduction see Wilkinson and Klaes (2012).

34 The category 'miscellaneous' covers underinvestment reasons rather specific to a particular type of climate investment. By contrast, the other categories in Table 1 possibly apply to more than one type. The label 'miscellaneous' does not mean the underinvestment reason at hand is unimportant. In fact, as this category is a 'catch all', it leaves room for failures or barriers of primary importance.

35 The chicken-and-egg barrier is relevant, too, for investment in hydrogen fuel cell vehicles, on the one hand, and the supporting fuelling infrastructure on the other hand.

36 The following and the observations on behavioural failures largely draw on Schleich (2007) and Gillingham *et al.* (2009).

37 A similar problem arises when decision makers have no incentive to go for profitable investments in energy savings. For instance, managers of public-sector buildings who are not rewarded – in one way or another – for embarking on profitable investments in energy savings are unlikely to pursue them. In these circumstances, lack of incentives follows from shortcomings in the institutional framework that governs decision making. This is distinct from the split-incentive problem, which is due to asymmetric information.

38 The annex at the end of this chapter substantiates this claim.

39 Jaccard (2005) provides an engaging review of hidden costs and, more generally, the challenge of making energy savings come true.

40 Policies aimed at saving trees to save the climate fly under the label REDD+, with the 'plus' indicating that the goal is not only to reduce emissions from deforestation and forest degradation, but also to promote conservation, sustainable forestry management, and forest carbon stock enhancement and to ensure that safeguards are in place to prevent the loss of existing forest in countries where deforestation has remained historically low.

41 At heart, climate change is a tragedy-of-the-commons problem: the atmosphere is a common-property sink for carbon and as long as there is free access to the sink, too much carbon is dumped too quickly into it.

42 *CCS* could also apply to biofuel-fired energy generation. In this case, the stock of greenhouse gases in the atmosphere falls if the production of biofuel feedstocks and fuel refining result in a net uptake of greenhouse gases from the atmosphere. Though this is typically assumed, it cannot be taken for granted. See, for instance, Searchinger *et al.* (2008) and Fragione *et al.* (2008).

43 The annex at the end of this chapter offers numerical illustrations.

44 In fact, one could argue that establishing property rights creates markets unless trading property rights is not permitted.

45 For completeness, note that subsidies could, in principle, be used to pay firms and individuals for not causing external damages – for instance, paying potential emitters of greenhouse gases for not emitting them. Such subsidies are problematic, to say the least. Not only do they use up budgetary resources (in contrast to taxing the negative externality that would generate government revenue); but more fundamentally, opportunistic behaviour will thrive when people are paid for not doing something.

46 The following rests on McKibbin and Wilcoxen (2002).

47 For completeness, note that low-carbon technologies, such as renewable electricity, have environmental advantages other than lower or no carbon emissions – *e.g.* lower or no sulphur dioxide emissions. But this would not make a subsidy in their favour a primary solution. The primary solution is cap-and-trade for sulphur dioxide as applied in the United States, for instance. That said, Europe chose flue-gas desulphurisation standards to contain sulphur dioxide emissions. Note, too, that subsidies for low-carbon investment, including feed-in tariff for renewable electricity, can be very effective in boosting investment. But that does not necessarily make them economically efficient. For a discussion of environmental effectiveness vs. economic efficiency see Finon (2007), for instance.

48 To get an idea of the size of the revenue forgone, consider the third phase of the EU ETS (2013-20). The cap is envisaged to decline from 1,974 million tonnes of CO_2eq in 2013 to 1,720 million tonnes in 2020, implying an average of 1,850 million emission permits (one permit per tonne) a year. Assume for illustrative purposes that 1.5 billion permits will be auctioned

each year. For a price decline of 10€/t, forgone revenue would amount to €15 billion a year.

49 In addition to the climate-change externality and the technology externality, a third external effect might come into play: support for low-carbon investment reduces the cost of low-carbon technologies relative to the cost of high-carbon ones not only in countries where this support is granted but in the rest of the world, too; this encourages the use of low-carbon technologies globally, thereby mitigating carbon emissions. Before cap-and-trade, subsidies for low-carbon technologies trigger this positive external effect. After cap-and-trade, it will result from a combination of carbon pricing and remaining subsidies. Kolev and Riess (2007, Box 1) offer an illustration of how this cost decline is indirectly induced by carbon pricing and directly caused by subsidies addressing technology externalities.

50 For a review of alternative policies to promote renewable energy, see Finon (2007).

51 See Mulder *et al*. (2007), for instance, for an in-depth discussion of the economics of strategic oil and gas reserves.

52 To give a flavour of the range of topics analysed: Abadie and Chamorro (2008) examine carbon-capture investment; Kjærland (2007) hydropower; Siddiqui *et al*. (2005) renewable energy research, development, demonstration, and deployment; and Muche (2009) pump-storage capacity.

53 For a recent survey see Allcott and Greenstone (2012). They conclude that "*the empirical magnitudes of the investment inefficiencies appear to be smaller, indeed substantially smaller, than the massive potential savings calculated in engineering analyses such as McKinsey & Co (2009)*". More specifically, they find that estimates of seemingly profitable energy-saving options do not properly account for factors such as hidden costs and the value of delaying investment in energy savings – as discussed in section 3.2 – and they point to research showing that once these factors are taken into account, many seemingly profitable energy-saving investments are not profitable after all. The authors also point to an emerging literature on the economic importance of informational problems. For instance, research in the United States suggests that the landlord-tenant problem (a subset of the asymmetric information problems discussed in section 3.2) might make residential energy use only one percent higher than it would be in the absence of that problem. While not negligible, it is not a big number either. See Keay (2011b) for another somewhat disenchanting assessment of the potential for economically efficient energy savings.

54 http://www.ukcip.org.uk
http://www.anpassung.net/cln_115/DE/Home/homepage__node.html?__nnn=true
http://climate-adapt.eea.europa.eu/

55 To be clear, this observation and those made in the rest of this chapter mainly refer to location-specific rather than country-wide climate risks.

56 A quote from Kahn (2010, p.27) is illuminating: "*A resident of Albany, New York,*

might wonder why his taxes are going up to rebuild part of the New Orleans coast. He might say to himself, 'I understand why my tax dollars go to pay for the military and to pay unemployment insurance – those help everyone – but why do I have to pay to rebuild New Orleans after a hurricane hits? How does that benefit me? Why can't coastal cities tax themselves and pay for their defences?' These are all good questions." One may add here that mankind concentrates in coastal areas and along rivers because of good economic opportunities in these locations, and within a given country, average incomes in these locations are typically higher than in the countryside. It follows that public adaptation investment paid for by higher levels of government run the risk of transferring funds from the poor to the rich.

57 This result and most that follow are rounded.

58 For completeness, note that even for $I_0 = 1000$ it would not be worthwhile to invest in $t = 1$ when there is small climate change.

Chapter 4: Green growth and green innovation

59 There is an extensive literature (most notably the *Report by the Commission on the Measurement of Economic Performance and Social Progress* by Stiglitz, J., Sen, A., Fitoussi, J.-P. (2009)) and a number of government and scientific committees that discuss potential welfare indicators to replace GDP (*e.g.*, there is a European Parliament resolution of 29 September 2011 that "*underlines that the Rio+20 Summit [in June 2012] should deliver an alternative model to measure growth and welfare 'beyond GDP'*")

60 In the following we will refer to GDP growth when we speak about (economic) growth.

61 For example, according to Smulders and Withagen (2011), when assuming "*good substitution, a clean backstop technology, a small share of natural resources in GDP, and/or green directed technical change*" and extending the model with natural resource inputs and pollution, as well as for endogenous technical change, decabonisation might lead to economic growth.

62 The Stern Review has not been directly included in the compilation of Tol (2009). The figure from the PAGE2002 integrated assessment model by Hope (2006) that served as a basis for the Stern Review is, however, included.

63 In Tol (2009) the estimates by Hope (2006) of 0.9 percent higher GDP for 2.5°C warming are included.

64 According to Tol (2011a), "*initial warming has positive effects – associated with carbon dioxide fertilisation, reduced winter heating costs, and lower cold-related mortality and morbidity*".

65 Incomes of countries are calculated using purchasing-power parity exchange rates and are discounted using an international interest rate that is the capital-weighted average of the real interest rates for different regions

66 See for example Wilson (2011) who argues that the US recovery programme spending on infrastructure had high job multipliers. Zandi (2008) estimates that out of 12 considered stimulus programmes, infrastructure spending has

the second highest multiplier effect (1.6). Pusch and Rannenberg (2011) indicate that the multiplier from government spending on construction is slightly higher than public consumption multipliers in most European countries.

67 European Parliament Press Release reference no. 20090505IPR55117

68 In addition there might be a feedback effect: as the price of oil falls (in response to investment in decarbonisation), demand for oil will increase also in Europe, offsetting some of the initial gain.

69 The focus on oil is comprehensible as oil represents the vast majority of the international energy trade and other energy prices are linked to some degree either explicitly (*e.g.*, gas contracts in Europe) or implicitly (*e.g.*, biodiesel) to the oil price.

70 Spencer *et al.* (2012), for example, argue that high oil prices were one of several triggers for the burst of the US subprime bubble because high oil prices *inter alia* reduced the disposable income of poorer suburban households.

71 COM(2010) 265 final.

72 Both values are quoted in 2008 prices.

73 Almost half of them are, however, still distributed for free to companies.

74 The same holds for reducing distorting subsidies on polluting activities.

75 On the other hand R&D subsidies might have negative effects in the absence of scale-effects of R&D as Segerstrom (2000) shows.

76 Of course, support to the deployment of renewable sources is not only justified by industrial policy motives. Other motives are: reducing emissions today by replacing fossil fuel sources, making renewable technologies competitive with fossil sources in order to enable emission reductions in the future and in countries without carbon pricing, and increasing security of supply.

77 The high cost of renewable support has encouraged some countries to significantly reduce their support for renewable energy. The slower expansion (or even decline) of some of the segments of the renewable energy market (*e.g.*, solar parks in Germany) has led to the market exit of some of the renewable technology producers.

78 The concentration of greenhouse gases in the atmosphere is measured in parts per million (ppm). To account for all (man-made) greenhouse-gases (*e.g.*, sulphur hexafluoride, which has a global warming potential 22,800 times that of CO_2), the concentration is measured in CO_2 equivalents.

79 A more 'physical' argument for why reducing energy inputs will reduce growth is given by Ayres and Warr (2009). Based on historic data on the link between energy availability and growth, they argue that *"if you constrain the amount of energy input into an economy without improving the efficiency for which the energy is used, you're constraining the amount of useful work you're delivering to people. And this will have very negative effects on growth"*. Hence if decarbonisation requires energy inputs to be reduced at a more rapid pace than potential technological improvements in energy efficiency, this will be

detrimental to growth.

80 For an emprical example, see Zachmann *et al*. (2011)

81 Breyer and Gerlach (2012) – provide empirical evidence

82 Huberty and Zachmann (2011) present empirical evidence for this

83 See for example Aghion *et al*. (2009)

84 Veugelers (2011) outlined this in the piece "Europe's clean energy Investment Challenge"

85 At the 2011 United Nations Climate Change Conference in Durban governments only agreed to establish a legally binding deal comprising all countries, which will be prepared by 2015, and to take effect in 2020.

86 OECD (2010) "Costs and effectiveness of the Copenhagen pledges: Assessing global greenhouse gas emissions targets and actions for 2020".

87 OECD (2010) "Costs and effectiveness of the Copenhagen pledges: Assessing global greenhouse gas emissions targets and actions for 2020".

88 See Tables 3 and 4 in section 4.3.6 for a breakdown of this figure.

89 In the absence of a second Kyoto commitment period the EU will only accept emission reduction certificates (CERs) from developing countries.

90 The over-allocation of allowances, the import of credits through the flexible mechanisms of the Kyoto protocol, the replacement of fossil fueled power generation by subsidised renewables, and the economic crisis have resulted in a high volume of allowances in the system. This causes the volume to exceed hedging demand by generators. Hence, intertemporal arbitrage is left to speculators. Those bank allowances, but do so at high future discount rate (requiring a high future return on investment). This results in a low current value of emission allowances (Neuhoff, 2012).

91 The cost of abating one additional unit of CO_2.

92 The UK Department for Environment, Food and Rural Affairs in 2008 estimated the average abatement cost implied by supporting biofuels at £104/tCO_2 (125 €/tCO_2). See DEFRA (2008), *Estimating the Cost-effectiveness of Biofuels*.

93 The political justification for lower French electricity prices is that electricity produced by the nuclear power plants of the state owned company EdF have marginal cost well below typical wholesale electricity prices in France and that French consumers should benefit from this 'nuclear rent'.

94 Numbers based on Eurostat data on the final consumption of electricity by households and the total populations of the countries.

95 However, due to a large number of confounding factors the picture is less clear than in the theoretical model. The German nuclear phase-out led to a decrease in nuclear power generation while the low natural gas prices and the balancing needs of intermittent renewables kept gas-fired power generation about constant.

96 Based on Eurostat data for total emissions and energy industry emissions in 2009.

97 This is well illustrated by the lack of a global climate agreement. The European strategy of a temporary and limited commitment to

decarbonisation (20 percent in 2020) is not encouraging an optimal decarbonisation pattern, but it provides the necessary political flexibility in case international climate negotiations continue to fail.

98 See the introduction of a tax on income from renewable feed-in tariffs in the Czech Republic (*e.g.*, a 26 percent tax on the revenue from solar PV systems larger than 30kW).

99 There are many questions on the practical implementation of a corresponding scheme that need to be studied carefully. One *ad-hoc* approach could be to auction a limited number of option contracts to investors. There might even be an initial revenue for the issuing public institution from the auctioning. Investors winning the option contracts would have to give back the options if they do not implement the corresponding carbon saving investments by a certain deadline.

100 For sake of simplicity this assumes collusion between the two companies – under oligopolistic competition the compensation would need to be bigger and under full competition the compensation would need to be €25 million.

101 Ferioli *et al.* (2009) suggest *"that cost reductions may not continue indefinitely and that well-behaved learning curves do not necessarily exist for every product or technology."*

102 The gross investment figures do not allow us to distinguish which part of the downturn is cyclical and which part is permanent.

103 A reason for such counter-cyclical behaviour might be that low interest rates in downturns increase investment.

104 A reason for such pro-cyclical behaviour might be that investors are encouraged by higher demand to invest more.

105 Of those grid investments one fifth is to be allocated to transmission, and four fifths to distribution networks.

106 This requires that at any point in time a substantial number of projects that are completely projected and approved is on the shelf.

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What is the optimal mix of policies to mitigate climate change and policies to adapt to it? How could climate action investment be boosted? How can decarbonisation become growth friendly? This report, written by economists from the Economics Department of the European Investment Bank and Bruegel, seeks to address those questions and come up with answers that are relevant especially in the European context.

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